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ABSTRACT

Presented is information recommended for inclusion in a short course to help extend knowledge of water resource development and research techniques in arid and semi-arid regions. Information is particularly intended for applicability in developing nations. Included are considerations of livestock grazing, use of hydrologic data, vegetation manipulation, watershed rehabilitation, water conservation practices in arid regions, and control of erosion. (RE)

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WATERSHED MANAGEMENT IN ARID ZONES

A PROTOTYPE SHORT COURSE

Agency for International Development

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held at

Saltillo, Mexico
March 1975

SCHOOL OF RENEWABLE NATURAL RESOURCES
UNIVERSITY OF ARIZONA
TUCSON, ARIZONA 85721

SE 029 261

PREFACE

Throughout the ages man has elected or been forced to settle in arid lands where water supplies were deficient, highly variable in availability, and often of inferior quality. Historically, people in arid regions have faced the challenge of water management head-on rather than quit their place of livelihood. Their efforts were abandoned only when water supplies completely failed, or were made useless by salinization, massive siltation, or floods. Painful rebuilding was usually undertaken by later generations who might re-invent the old methods and make the same mistakes that often led to even greater failures as the resource base was progressively depleted. Most often, the reasons for failure lay more in the neglect of man to follow to rules of nature than in the capriciousness of nature.

The same process continues, to greater or lesser extent, in all arid regions of the world today. Old techniques are being re-discovered or invented anew, and many of the old mistakes are being repreated. The difference now is a technology capable of accomplishing great works for the benefit of man or producing failures on a grand scale.

With the increasing world-wide necessity to provide living space, food, and a better way of life for ever increasing populations, the arid lands of the world, through modern technology, are becoming a new frontier. Mexico is part of this frontier--a frontier that can only be developed by intensive research, knowledge of past successes and failures, and hard work.

An important need in advancing this frontier in the developing nations, exemplified by many of the problems in Mexico, is for information on methodologies of watershed management for arid and semiarid regions. These regions cover 30 percent of the earth's land surface and contain a large percent of its population, most of which is in the developing nations.

This volume evolved from a short course given in Saltillo, Mexico during March 1974 which was designed to help extend knowledge of water resource development and research techniques in arid and semiarid systems applicable to the developing nations. The course was sponsored by USAD under the 211d Grant program and contract AID/CM/TA-147-491. Its purpose was to serve as a prototype for subsequent courses that might be given in other developing countries to extend the work being accomplished by a consortium of the University of Arizona, Colorado State University, Utah State University, The University of California at Riverside and Oregon State University under the USAID 211d program. The course was developed in cooperation with Centro Nacional de Investigacion Para Zonas Aridas and the Universidad Autonoma Agraria Antonio Narro of Mexico. Some of the subject matter is general, some more specific, but it is aimed at the needs expressed by the Mexican cooperating agencies, needs that are experienced to some degree in many of the developing nations.

John L. Thames
John N. Fischer

November 15, 1975

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RANGE CONDITION

Phil Ogden[1]

INTRODUCTION

As researchers and resource managers consider data collection and techniques for management of watersheds for soil stability and/or water yield, they are immediately faced with the complexity of the watershed resources with which they must work. These complexities are not only in vegetation, soils, topography, and climate but also in differences in uses such as livestock and wildlife grazing. The watershed manager must recognize that grazing influences differ among soils and vegetation communities on watersheds. An initial step in reducing the soil and vegetation complexity is to identify management units which are homogeneous enough that research data may be extrapolated from one unit to another and to which similar management techniques apply.

RANGE SITES

A basic unit of land classification which has been utilized in range evaluation, especially by the U.S. Soil Conservation Service, has been the range site. A range site as defined by the Range Term Glossary Committee (1964) is:

> An area of land having a combination of edaphic, climatic, topographic and natural biotic factors that is significantly different from adjacent areas. These environmental areas are considered as units for purposes of discussion, investigation and management. Changes from one site to another represent significant differences in potential forage production and/or differences in management requirements for proper land use.

Within a specified precipitation zone, topographical position (bottomland, upland, ridge, etc.), slope, aspect, and soil factors combine to create range sites. Each site has a potential to produce specific plant and animal communities and sediment and water yield within a watershed. Sometimes range sites within the watershed are of large enough extent that they may be mapped and managed as separate entities, but often they occur in patterns where only complexes of sites can be mapped. Sampling, however, should be accomplished at the site level. It is at the range site level that the researcher and manager can correlate treatments and results and, thus, make sense from otherwise unrelated data. Aerial photography is an excellent aid in identification and delineation of range sites within a watershed.

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[1] Professor of Range Management, University of Arizona

RANGE CONDITION AND TREND

Each range site has a potential to grow specific plants with a level of vigor, ground cover, and erosion protection which can be called excellent for the site. This potential, or excellent condition, for each range site can be determined by observing well managed areas. Range condition is defined as the current status of vegetation and soil compared to the potential for the site. Thus, range condition is excellent, good, fair, or poor depending on characteristics of the site at the present compared to what it is capable of producing.

The concept of range condition requires that some potential characteristics of vegetation and soil be established for each site against which current characteristics can be compared. In the United States, ungrazed portions of sites have often been used to establish the potentials. This has been criticized on the basis that ungrazed conditions are not a reasonable management goal. The researcher or manager has two ways by which he may avoid this criticism. One way is to define the potential as the vegetation and soil characteristics which can be attained under what is considered good management. The second alternative is to define potential in terms of ecological climax vegetation without livestock grazing but set the management goal for the condition level which maximizes returns and provides stability to the watershed. I prefer this latter approach, if ungrazed areas can be found as a basis for establishing potential.

Plant species composition (relative abundance of a species in the plant community) is one of the most important characteristics related to range condition. There is a dynamic relationship which exists between soils and plant communities on each range site. As plant communities occupy a range site, they in turn modify the site by changing the soil nutrients, water holding capacity, and other factors. These new conditions enable other plant communities to replace the existing communities on the site. This succession of one plant community replacing another continues until a plant community exists which maintains itself on the site (climax community). Figure 1 represents plant community development on a site with fluctuations created by weather cycles. Note that there is a general development toward a climax plant community for the site but periods of dry weather cause a retrogression of this development. Vegetational succession on a site may also be reversed by excessive grazing, fire, plant diseases, or mechanical disturbance of the site. Correct management decisions require the knowledge of the condition of the vegetation of each site, whether the trend is toward succession or retrogressing, and the cause for the current situation.

Dyksterhuis (1949) developed a quantitative method of evaluating range condition based on plant composition which has been widely used by the U.S. Soil Conservation Service. His method classes plants as decreasers, increasers, and invaders. Decreaser plants are those which decrease in abundance, at least initially, with heavy use. Invaders are not present on a site in excellent condition but invade the site as decreasers and increasers no longer fully occupy the site. For evaluation of condition, site locations are selected which are producing what is considered to be the potential vegetation for the site. Guides are established for the range site in this excellent condition, listing the plants as decreasers, increasers, or invaders for the site. Increaser plants are given a maximum percentage composition value at which they occur (percentage allowable toward condition score) on the site in excellent condition. Table 1 shows a hypothetical guide for a range site. The evaluation of condition in the field is made by estimating plant composition on the site to be evaluated and comparing with the guide. Composition must be based on the same

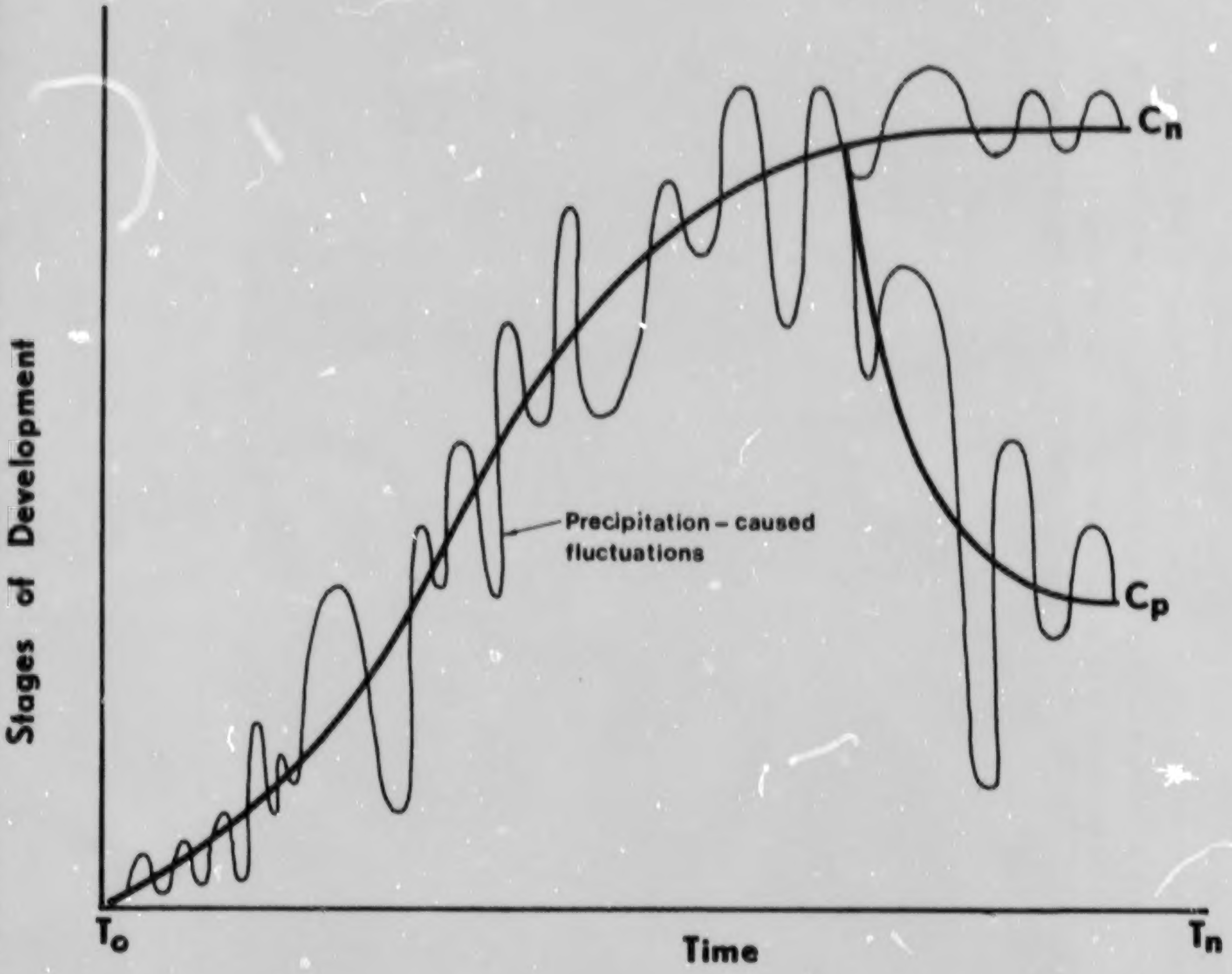
Stages of Development
Precipitation – caused fluctuations
C_n
C_p
T_o
Time
T_n

Fig. 1. General plant community succession to a natural climax (C_n) with variations caused by precipitation variability and retrogression to a deteriorated plant community (C_p) induced by overgrazing (modified from Heady 1973).

criteria as the guide but may be based on cover or weight.

Table 1. Range condition guide for a sandy upland range site receiving 300 mm of annual precipitation. Plant composition based on percentage by weight.

Decreasers (count all of percentage composition toward condition score)	Increasers (count only percentage allowable toward condition score)		Invaders (count none toward the condition score)
		Percentage Allowable	
Species	Species		Species
A	D	30	G
B	E	10	H
C	F	5	

Table 2 shows field data for a sandy upland range site and calculation of range condition score. Scores of 0-25 are poor condition, 26-50 fair, 51-75 good, and 76-100 as excellent condition. Plant cover, litter accumulation, plant vigor, current erosion and other factors may also be utilized to evaluate site condition estimates.

Table 2. Field data as percentage plant species composition by weight from sandy upland range site and calculation of a range condition score.

Species	Percentage Composition by weight	Contribution to condition Score
A	10	10
B	10	10
D	60	30
F	10	5
H	10	0
Total	100	55

Condition Score is 55, which is Good condition.

Change in range condition over time is trend. Evaluation of trend helps to monitor use influences on range sites on a watershed.

PLANT GROWTH INFLUENCED BY GRAZING

For an understanding of why overgrazing causes vegetation retrogression, it is appropriate to review a few basic plant growth requirements. Each plant growing on the range functions as a converter of solar energy to chemical energy stored in organic compounds. The process by which this is accomplished is photosynthesis which takes place in the green leaves of plants. The chemical energy formed by the plant is utilized by the plant to make root growth and herbage growth, produce seed, and develop winter or drought hardness. Also it may be stored in roots and stem bases to be used to initiate growth following winter or drought dormancy. Without adequate leaf material left on a plant, it is unable to convert adequate energy to meet its needs for survival. This chemical energy converted by plants is also the source of energy for animal populations which obtain forage from rangelands.

The energy reserves stored in the roots and stem bases of plants is reduced to its lowest levels at the time a plant first initiates growth after a period of winter or drought dormancy. Figure 2 shows the accumulation and depletion of carbohydrate reserves in sideoats grama (Bouteloua curtipendula) growing in southern Arizona. Close and continued grazing when reserves are low, so there is no opportunity to replenish reserves, is extremely harmful to plant vigor. After growth has been well started, however, most plants can function effectively and continue to carry on adequate photosynthesis if no more than 50% of their herbage weight is removed.

With close and continued overgrazing, growth is reduced, seeds are not developed, and the plant is reduced in vigor to the extent it is unable to withstand drought or cold or to make regrowth after dormancy. In addition, if grass plants are grazed too closely, the growth buds at the base of the plant are exposed to the temperature extremes of hot in the daytime and cold at night and to extreme drying. Adequate plant

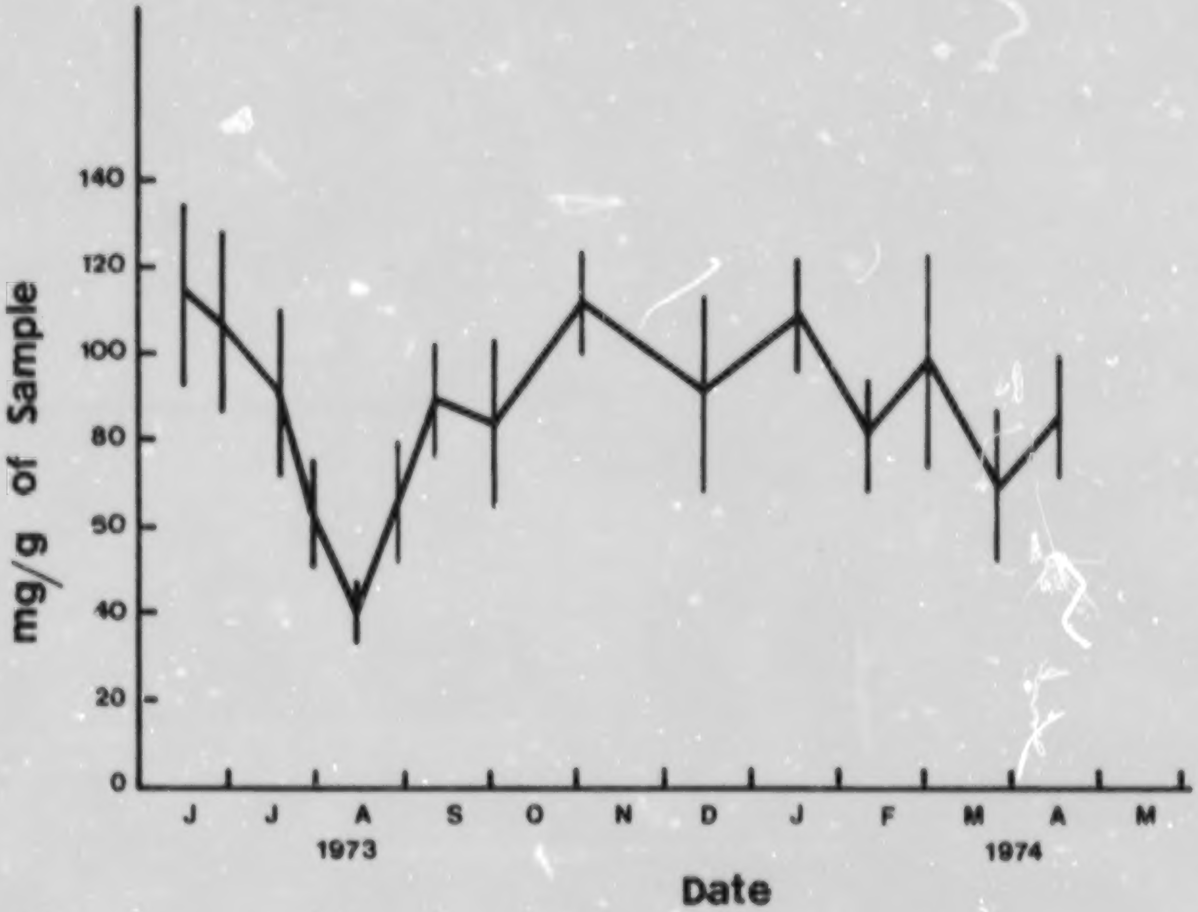

Fig. 2. Carbohydrate reserves as glucose equivalents in roots of sideoats grama collected from The Research Ranch, Elgin, Arizona. 95 percent confidence interval is shown for each sampling date (Sule 1974).

material left at the base of plant protects the tender new buds which produce the next crops of herbage.

Individual plants vary greatly as to their sensitivity to closeness of grazing and season of grazing. This variability and their different ability to withstand droughty sites account in part why some plants decrease, and some increase in abundance with close grazing. Combined with this is the difference in preference of livestock for different plants. Grazing puts a stress on palatable plants which is not given to unpalatable plants.

SITE CHARACTERISTICS INFLUENCED BY GRAZING

In addition to the influences of overgrazing on individual plants, there are general influences to the soil and plant community. Probably the greatest influence caused by overgrazing is the reduction in vegetative cover, thus increasing compaction of the soil from rain drop impact and increasing water movement over the soil surface. Removal of vegetation by grazing also may reduce organic matter added to the soil which influences soil structure. Removal of vegetation may also alter the microclimate at the soil level to increase the soil temperature and, thus, moisture lost by evaporation. Added to these influences are animal influences on soil compaction and creating trails along which water may flow. The effect of these influences is that overgrazing may create a situation of less available water for plant growth and the retrogression caused by the overgrazing is expressed similar too, and difficult to distinguish from, a downward trend associated with drought.

The watershed manager, then, must recognize that grazing does influence sites within watersheds and should work with livestock producers to develop grazing levels and systems which are of mutual benefit. For most watersheds, there are levels and systems of grazing which are compatible with watershed stability.

LITERATURE CITED

Dyksterhuis, E. J. 1949. Condition and management of range land based on quantitative ecology. J. Range Manage. 2:104-115, illus.

Range Term Glossary Committee. 1964. A glossary of terms used in range management. American Society of Range Management. Portland, Oregon. 32 pp.

Heady, Harold F. 1973. Structure and function of climax. In D. N. Hyder (ed.), Arid shrublands. Proc. of the Third Workshop of the United States/Australia Rangelands Panel. Tucson, Arizona.

Suel, Bello. 1974. Growth, development and carbohydrate reserves of sideoats grama (Bouteloua curtipendula) and plains lovegrass (Eragrostis intermedia). M.S. Thesis, University of Arizona. 36 pp.

LIVESTOCK GRAZING MANAGEMENT TO IMPROVE WATERSHEDS

Phil R. Ogden[1]

INTRODUCTION

The intensity and amount of rainfall are the major factors influencing runoff and sediment yield from a watershed. The watershed manager cannot control these factors directly, but he can influence their effect by managing the vegetation on the watershed. Livestock exert a major influence on vegetation. Thus, if grazing is a use of the watershed, then watershed management plans must include provisions for grazing management. This paper discusses some of the general considerations which must be the basis for all grazing management programs.

CONSIDERATIONS AS A BASIS FOR GRAZING MANAGEMENT

The quantity of forage produced, the season or seasons it is produced, and dependability of the production is a first consideration. A cow and calf (considered as an animal unit or roughly 1,000 pounds of live animal weight) require about 900 pounds of range forage per month. This requirement must be met with less than half of the herbage and browse production on each range site, because at least half of the production should be left on the watershed to maintain vigor of plants growing on the watershed and provide for ground cover, organic matter return to the soil, and maintain a favorable microclimate on range sites on the watershed.

If the major forage production occurs during a single season, then forage must be utilized both to provide forage for livestock and to maintain soil cover of the range throughout the year. Livestock grazing capacity may be limited by the number of animals which can be carried during the dormant periods of vegetation. Herbage and browse production should be managed so that there is adequate provision for watershed protection at the end of dormant periods and prior to major growing seasons. Drought is common in dry climates, and plants may not have enough vigor to recover full production after dry periods, especially if the period extends over more than one season. Stocking, therefore, should be flexible to adjust to a variable forage supply.

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The variability of the physiological and morphological growth characteristics of individual plants also influence management. Plants on the same range site may differ in growth characteristics and respond differently to grazing pressure in different seasons. When planning grazing management systems, it is important to know, at least for the major plant species, the periods of new shoot development, carbohydrate depletion and accumulation curves, periods of major new root growth, time of seed production, etc. These characteristics influence the capability of different plants to benefit from periods of rest from grazing and their susceptibility to damage by close grazing at specific seasons.

In addition to the variability in response of individual plants to grazing, there is variability in livestock preference. The preference may be for specific species at any season or may be a seasonal preference for different species. A major objective of any grazing management system should be to even out the use among plants on the range, so that forage production comes from many plants and not just a few selected species which receive all of the grazing pressure. If one or more major species tend to receive a greater portion of the grazing pressure and are heavily grazed before other species are used, then some management scheme must be used to give these plants a rest. If use cannot be shifted to associated species, the total grazing capacity must be based on the level of use which can be tolerated by the most preferred species.

If topography, vegetation and soils are variable on a watershed, distribution of livestock use over the range may be poor. Livestock tend to use some areas more heavily than others, especially near water, along level bottomlands, ridges, and certain range sites. They may avoid steep slopes, some soils, and dense brush. An attempt to attain uniform livestock use over the range also should be a major objective of any management plan.

The requirements of the livestock must also be considered in any management system. Besides the total intake requirement for forage discussed above, this forage must be of a quality to meet their nutritional needs. We are usually concerned with meeting nutritional requirements in four catagories when dealing with range forage: protein, energy, phosphorus, and carotene. All of these nutrients are generally at a satisfactory level when adequate green forage is available. Browse species, however, usually do not contain adequate energy, and dry grass is low in protein, phosphorus, and carotene. If palatable browse species are present on the range along with grass, nutritional requirements can often be met from range forage. If not, some supplementation is necessary. A high nutrition plane is especially important at the time of livestock breeding if a high percentage of the cows are to breed, especially while they are maintaining a calf.

Livestock grazing management programs may also require that special care be taken of young replacement heifers to provide them with the special handling and feed required for their maximum production. It may also be necessary to maintain bulls separately from the cows for some parts of the year. Cows should be available for observation and for branding and handling calves at time of calving and convenient for rounding up at time of weaning calves and shipping. The livestock grazing management program should not emphasize these livestock care requirements to the detriment of the watershed resource, but the overall plan, to be effective, must also take into account these livestock handling needs.

ESTABLISH SPECIFIC MANAGEMENT OBJECTIVES

In general, the plan may be directed at providing maximum livestock production, yet maintaining or improving watershed stability. For any specific watershed, however, the goals should be outlined in more detail, identifying the range sites and even the specific species which are used as the key plants for which management is directed. If a specific area of the watershed is in need of improvement in vegetation cover, specify this as an objective of the grazing management system. Design management to fit the specific objectives.

IMPLEMENTATION OF GRAZING MANAGEMENT

An inventory of forage available on the watershed is necessary to determine the livestock grazing capacity. Then regulation of livestock numbers so that they are in balance with the forage supply at a level of use which maintains plant vigor and watershed stability is often the major problem which must be solved in implementation of proper grazing management. The level of forage use which will maintain range condition is very dependent on the specific range site, season of use and plants being grazed. A general estimate is to utilize 50% and leave 50%. A proper level of grazing is usually consistent with long term goals of sustained production for a livestock operation but is not always consistent with short term economic goals of private livestock producers. Educational programs aimed at showing long term goals in terms of society needs and presented to livestock producers and the general public are necessary parts of this implementation of proper livestock numbers grazing a range. Ideally, livestock producers should participate in plans for proper stocking if it is to be successful, for they are the persons responsible for the success or failure of grazing management programs. Political and social pressures, however, may be necessary to accomplish proper levels of livestock grazing on watersheds.

Balancing livestock numbers with the forage supply should include procedures to provide flexibility to these numbers to adjust to good and bad forage years with provisions in the management for heavy culling and sale of extra animals in drought years. The alternative is to stock at a conservative level, so that the watershed is protected even in drought years. The provision for flexibility is a better alternative if it can be accomplished.

Livestock use distribution on ranges usually can be improved by well-planned water developments, because livestock can be attracted to areas where they would not use the forage because of a lack of water.

In dry climates, controlling livestock access to water and riding to move livestock from one area to another is a means of regulating areas of livestock concentration. Fencing may be used to regulate where livestock may graze, and trails may be constructed in rough or brushy country to help move livestock from one area to another to obtain more even distribution. Salt also may be used to some extent to attract livestock to areas which would otherwise be little used.

Fencing and water developments may also be utilized to plan a system of grazing so livestock use is regulated at specific seasons to specific areas of the range while resting plant species on other portions of the range. The periods of rest should be designed to enable certain plant species to improve plant vigor by allowing them to make root growth, to seed, replenish carbohydrate reserves, initiate new shoots or to meet a combination of these growth requirements which could not be met under a yearlong grazing period. There are numerous systems of grazing recommended around the world, but any successful system must fit the local conditions if it is to be of any value. Too often grazing systems have been instituted which were not based on local needs; thus, they have not been an improvement over yearlong grazing.

Good livestock husbandry and correct management practices combine to provide efficient conversion of the range forage to marketable protein. The test of an efficient range livestock operation could well be the pounds of range forage consumed to produce a pound of marketable meat. In today's world of protein and energy shortages, this is an important contribution of well-managed range lands.

MONITOR RESULTS OF GRAZING PLAN

After a grazing plan is put into effect on a watershed, a monitoring program should be established to measure results in terms of range condition on the watershed, on livestock productivity, and other aspects of the watershed which would show influence of the grazing management program. Set up the monitoring program to specifically test whether the objectives of the plan, as initially established, are being met. If the objectives are not being met, determine the causes and make appropriate changes. No management should be static. As more information is gained and objectives change, the plan should be flexible to the changes. But be careful that changes are consistent with the objectives of the watershed management and are not changes to satisfy temporary pressures which may not be in accord with the primary objectives as established.

PRECIPITATION ADEQUACIES AND FORAGE PRODUCTION IN MEXICO

George H. Hargreaves[1]

INTRODUCTION

Watershed management for increased forage production requires some means of determining an approximate potential level of productivity. Forage production is influenced by soils, climate, fertility, management, and other factors. A good knowledge of one factor makes it easier to evaluate the others.

Methods are given for the estimation of potential water use and for making approximate comparisons between potential use and dependable supply from precipitation. Moisture adequacy is related in a general way to forage production. Moisture availability indices are presented for the locations for which climatic data are available in Mexico.

Although the purpose of this study is to provide useful data for the improvement of watershed management, the values of estimated potential evapotranspiration or potential water use are also valuable in estimating irrigation requirements and in scheduling irrigation applications.

The information presented is based upon extensive review of the literature on water requirements and the relationships between moisture availability and crop and forage production. However, basic formulas and procedures are given without discussion of theory or scientific development of the procedures. For those wishing more detailed information, additional references and explanation can be furnished upon request.

DEFINITION OF TERMS

Potential Evapotranspiration, ETP, is the amount of water evaporated and transpired from actively growing, short green plants (usually grass) with a full crop cover and a continuously adequate moisture supply. It is considered to be dependent upon the climate and can be estimated from climatic parameters, the most important of which are available incoming radiation, temperature, and relative humidity. The incoming radiation is related to the extraterrestrial radiation that reaches the outer atmosphere and the factors that influence its transmission through the atmosphere, such as the percentage of possible sunshine or cloudiness. These climatic parameters are not independent of each other, but are interrelated in a complex manner. Evapotranspiration from grass (as measured by Pruitt (1966) at Davis, California, using twenty-foot diameter weighing lysimeters) is used as the standard for potential evapotranspiration.

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The ASCE Technical Committee on Irrigation Requirements (1973) has used potential evapotranspiration as defined for alfalfa. Potential evapotranspiration from grass, as used herein, is about 80 to 87 percent of that from alfalfa.

Actual Evapotranspiration, ETA, is the actual use of water by agricultural crops including direct evaporation from moist soils and wet vegetation. It depends on the climate, the crop, and the soil moisture supply. The climatic factors are considered in the estimation of potential evapotranspiration. Crop factors used to calculate ETA from ETP include the stage of growth, percentage of ground cover, height and total leaf surface. Evapotranspiration is limited by soil moisture availability within the root zone and by some crop characteristics.

Dependable Precipitation, PD, is the precipitation that has a specified probability of occurrence based on an analysis of long-term precipitation records. For irrigation development, a 75 percent probability level, or the rainfall that may be expected to occur three years out of four years, has been selected as a reasonable value for most conditions. For some drought sensitive or high value crops, or special conditions, a different probability level may be more appropriate.

Moisture-Availability Index, MAI, is a measure of the adequacy of precipitation in supplying moisture requirements. It is computed by dividing the dependable precipitation by the potential evapotranspiration. (MAI = PD/ETP)

Adequacy Percentage, AP, is the percentage of years in the precipitation records during which precipitation for any given month equals or exceeds the potential evapotranspiration for the same month.

Moisture Deficit, ETDF, is the difference between potential evapotranspiration and dependable precipitation. A moisture excess is indicated by a negative deficit. (ETDF = ETP - PD)

Precipitation Deficit, PREC DEF, is the difference between potential evapotranspiration and the mean monthly precipitation, PM. An excess is indicated by a negative deficit. (PREC DEF = ETP - PPM)

Effective Precipitation, EFF PREC, is the amount of precipitation stored in the effective plant root zone and used in the production of vegetative growth. It excludes surface runoff and percolation beyond the reach of the plant roots. Although effective precipitation is not used in the analyses presented herein, consideration should be given to soil depth, infiltration rates, management practices, water spreading and other factors and practices that influence the effectiveness of precipitation.

METHODS FOR ESTIMATING POTENTIAL EVAPOTRANSPIRATION

Many methods are available for calculating or estimating potential evapotranspiration, ETP. In this study, two methods are presented. Emphasis is placed upon methods that require a minimum of climatic measurements, have simplicity and ease of computation, and provide accuracy of estimation.

Radiation Method. Many technicians have related potential evapotranspiration, ETP, to some measurement of radiation combined with temperature. Hargreaves (1974) found the same degree of correlation between ETP and net radiation, RN, as with incident solar radiation, RS. Hargreaves and Allan (19--) found that ETP, in mm per month, can be estimated from the equation

$$ETP = 0.004 \times TMF \times RS \quad \ldots\ldots\ldots \quad (1)$$

in which TMF is mean temperature, in degrees Fahrenheit, and RS is solar radiation in Langleys per day.

Equation 1 is an approximation, that does not correct for the latent head of vaporization, L., and the number of days in the month, DM. The latent heat of vaporization is given by the equation

$$L = 595.9 - 0.55 \times TM \quad \ldots\ldots\ldots \quad (2)$$

in which TM is mean temperature in degrees centigrade. For temperature in degrees Fahrenheit, TMF, the equation is

$$L = 595.9 - 0.305 \times (TMF - 32) \quad . \; . \; . \; . \; . \; . \quad (2a)$$

Solar radiation, RSM, in equivalent mm per month, is given by the equation

$$RSM = DM \times 10 \times RS/L \quad . \; . \; . \; . \; . \; . \; . \; . \; . \quad (3)$$

Potential evapotranspiration, in mm per month, is estimated by the equation

$$ETP = 0.0075 \times RSM \times TMF \quad . \; . \; . \; . \; . \; . \; . \; . \quad (4)$$

Solar radiation measurements are available for Mexico in only a few locations and some radiometers may be poorly calibrated. However, Lof, Duffie and Smith (1966) present maps for each month with isolines showing daily means of incident solar radiation in Langleys per day (gram calories per square centimeter per day). From these maps monthly values of radiation were tabulated for the climatic stations in Mexico for which data on temperature and precipitation were available. Equation 4 was then used to calculate potential evapotranspiration, ETP, for each of the climatic stations.

Humidity Method. Where data are available for mean 24-hour relative humidity, HM, in percent, an equation given by Hargreaves (1974) can be used to estimate ETP. This equation can be written

$$ETP = MF \times TMF \times CH \quad . \; . \; . \; . \; . \; . \; . \; . \; . \quad (5)$$

in which MF is a monthly latitude factor based upon radiation and day length, and (for latitudes of more than 35 degrees from the equator) a correction for sun angle CH is a coefficient for relative humidity

$$CH = 0.166 \times (100 - HM)^{1/2} \quad . \; . \; . \; . \; . \; . \; . \; . \quad (5a)$$

with a maximum value of CH of 1.00. Values of MF in both inches per month and mm per month are given in Tables 1 and 2 for latitudes 14 degrees to 33 degrees North.

From a correlation analysis using 8 years of lysimeter data furnished by Pruitt (1974), equations 4 and 5 are indicated to be about equally accurate and reliable ($R^2 = 0.98$ for equation 4 and $R^2 = 0.97$ for equation 5). The two equations have also been compared using data from various states and countries. Differences in results appear to be within the limits of accuracy in measuring radiation and relative humidity.

For the 274 climatic stations used in this study, a computer comparison was made of equations 4 and 5. Data on relative humidity were not available and for that reason, a value of CH = 1.00 was used. Values of

TABLE 1 MONTHLY LAT. FACTOR,MF, FOR ESTIMATING POTENTIAL EVAPOTRANSPIRATION IN INCHES

NORTH LAT	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
					MONTH							
33	.040	.048	.073	.091	.111	.116	.116	.102	.079	.060	.042	.037
32	.042	.049	.074	.091	.111	.115	.116	.102	.080	.061	.044	.039
31	.043	.050	.074	.092	.110	.114	.115	.102	.080	.063	.045	.040
30	.045	.052	.075	.092	.110	.113	.114	.102	.081	.064	.047	.041
29	.046	.053	.076	.092	.109	.112	.113	.102	.082	.065	.048	.043
28	.048	.054	.077	.092	.109	.111	.112	.102	.082	.066	.050	.044
27	.049	.055	.078	.093	.108	.110	.112	.102	.083	.067	.051	.046
26	.051	.056	.079	.093	.109	.109	.111	.101	.083	.069	.052	.048
25	.052	.058	.080	.093	.107	.108	.110	.101	.084	.070	.054	.049
24	.054	.059	.081	.093	.106	.107	.109	.101	.084	.071	.055	.051
23	.056	.060	.081	.093	.106	.106	.108	.101	.085	.072	.057	.052
22	.057	.061	.082	.093	.105	.105	.107	.100	.085	.073	.058	.054
21	.059	.062	.083	.093	.104	.104	.106	.100	.086	.074	.060	.056
20	.060	.063	.084	.093	.104	.103	.105	.100	.086	.075	.061	.057
19	.062	.065	.084	.093	.103	.102	.105	.099	.087	.076	.062	.059
18	.063	.066	.085	.093	.102	.101	.104	.099	.087	.078	.064	.060
17	.065	.067	.086	.093	.101	.100	.103	.099	.087	.079	.065	.062
16	.066	.068	.086	.093	.101	.099	.102	.098	.088	.080	.067	.063
15	.068	.069	.087	.092	.100	.098	.101	.098	.088	.080	.068	.065
14	.069	.070	.087	.092	.099	.097	.100	.097	.088	.081	.069	.067

TABLE 2 MONTHLY LATITUDE FACTOR,MF, FOR ESTIMATING POTENTIAL EVAPOTRANSPIRATION,ETP,IN MM.

NORTH LAT	MONTH JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
33	1.02	1.21	1.84	2.32	2.83	2.94	2.95	2.59	2.01	1.52	1.07	.93
32	1.06	1.25	1.87	2.32	2.82	2.92	2.93	2.59	2.02	1.56	1.11	.97
31	1.10	1.28	1.89	2.33	2.81	2.89	2.91	2.59	2.04	1.59	1.15	1.01
30	1.14	1.31	1.92	2.34	2.79	2.87	2.90	2.59	2.06	1.62	1.18	1.05
29	1.17	1.34	1.94	2.34	2.78	2.85	2.88	2.59	2.07	1.65	1.22	1.09
28	1.21	1.37	1.96	2.35	2.76	2.82	2.85	2.58	2.09	1.68	1.26	1.13
27	1.25	1.40	1.99	2.35	2.75	2.80	2.83	2.58	2.11	1.71	1.30	1.17
26	1.29	1.43	2.01	2.35	2.73	2.77	2.81	2.57	2.12	1.74	1.33	1.21
25	1.33	1.46	2.03	2.36	2.72	2.75	2.79	2.57	2.13	1.77	1.37	1.25
24	1.37	1.49	2.05	2.36	2.70	2.72	2.77	2.56	2.15	1.80	1.41	1.29
23	1.41	1.52	2.07	2.36	2.69	2.70	2.75	2.56	2.16	1.83	1.44	1.33
22	1.45	1.55	2.09	2.36	2.67	2.67	2.72	2.55	2.17	1.86	1.48	1.37
21	1.49	1.58	2.11	2.36	2.65	2.65	2.70	2.54	2.18	1.89	1.51	1.41
20	1.53	1.61	2.13	2.36	2.63	2.62	2.68	2.53	2.19	1.92	1.55	1.45
19	1.57	1.64	2.14	2.36	2.61	2.59	2.65	2.52	2.20	1.94	1.59	1.49
18	1.60	1.67	2.16	2.36	2.59	2.57	2.63	2.51	2.21	1.97	1.62	1.53
17	1.64	1.70	2.18	2.35	2.58	2.54	2.61	2.50	2.22	1.99	1.66	1.57
16	1.68	1.72	2.19	2.35	2.56	2.51	2.58	2.49	2.23	2.02	1.69	1.61
15	1.72	1.75	2.21	2.35	2.53	2.48	2.55	2.48	2.23	2.04	1.73	1.65
14	1.76	1.78	2.22	2.34	2.51	2.46	2.53	2.47	2.24	2.07	1.76	1.69

relative humidity required to make the two equations approximately equal were calculated, indicating a range of from fairly low humidities up to a maximum annual average of 81 percent. This range looks quite reasonable. The median value for relative humidity arrived at by this procedure was 75 percent.

Errors in measuring incident solar radiation are more often on the low side. This would result in somewhat higher than actual values for relative humidity in the comparison. However, agreement between the two procedures was surprisingly good and mean errors in estimating ETP are probably in the order of about 10 percent or less.

ESTIMATION OF DEPENDABLE PRECIPITATION

The 75 percent probability of precipitation occurrence was selected as an index for comparing moisture available from rainfall in one area with that in another. The precipitation equaled or exceeded three years out of four is used in computing the moisture availability index, MAI. For forage production, a severe deficiency in any given month with a probability of occurrence one year in four would not be seriously limiting on the watershed carrying capacity or on agricultural usage.

Areas with higher average precipitation usually have a greater dependability of precipitation. An analysis was made of the relationship between mean monthly rainfall, PM, and the 75 percent probability of precipitation, PD. For those months having values of PD of 10 mm or more, regression and graphical analyses were made for various states and regions. For areas having fairly regular rainy seasons such as the Eastern United States, Central America, most of Venezuela, Colombia, and Ecuador, the relationship can be written

$$PD = -10 + 0.70\ PM \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (6)$$

in which PD and PM are expressed in mm per month. Equation 6 may overestimate the dependability of precipitation for the more arid portions of Mexico. However, in the absence of data adequate for probability analyses, the equation is recommended for use.

On an annual basis, the 75 percent annual probability, PDA, in mm, can be estimated from mean annual precipitation, PMA, from the equation

$$PDA = -120 + 0.90\ PMA \quad . \quad . \quad . \quad . \quad . \quad . \quad . \qquad (6a)$$

MOISTURE AND FORAGE PRODUCTION

Forage yields depend to an important degree upon moisture availability. Various stages of growth are more sensitive to moisture deficits than others. Based upon limited data from fertilization of dry farmed wheat, moisture would need to exceed one third of adequacy before positive response to fertilization can be anticipated. Similar relationships probably hold for forage crops.

If Y is used to represent a ratio of yield to the maximum yield under the prevailing fertility and cutural conditons and X is the ratio of the actual moisture available from rainfall plus irrigation to the amount for which the yield is a maximum, then yield data from various crops can be compared. Considerable data are available from a variety of crops in the range of X from 0.35 to 1.00. Although timing of moisture deficits can greatly influence yields, most available yield data indicate a general relationship between moisture availability and yield. This relationship is given by the equation

$$Y = 0.8X + 1.3X^2 - 1.1X^3 \quad . \quad . \quad . \quad . \quad . \quad . \quad . \qquad (7)$$

The first derivative of Equation 7 is

$$dY/dX = 0.8 + 2.6X - 3.3X^2 \quad . \quad . \quad . \quad . \quad . \quad . \qquad (8)$$

For the range, $X = 0.09$ to $X = 0.70$, dY/dX is 1.00 or more with a maximum value of 1.31 when X is 0.394. This indicates a maximum increase in production per unit of moisture available at about 40 percent of moisture adequacy. These relationships are presented graphically in Fig. 1.

Equation 7 is based upon actual application of water. Use of ETA/ETP instead of values of X results in an approximate straight line relationship with Y for the production of forage or dry matter for many crops.

It would seem desirable to develop some form of standard classification for measuring moisture adequacies or deficits from the atmosphere, and to modify this for distribution or special soil and forage or crop conditions as the necessity arises. Hargreaves (1972) proposed that MAI be adopted as a standard index for measuring water deficiencies and excesses, and that the following classification be used:

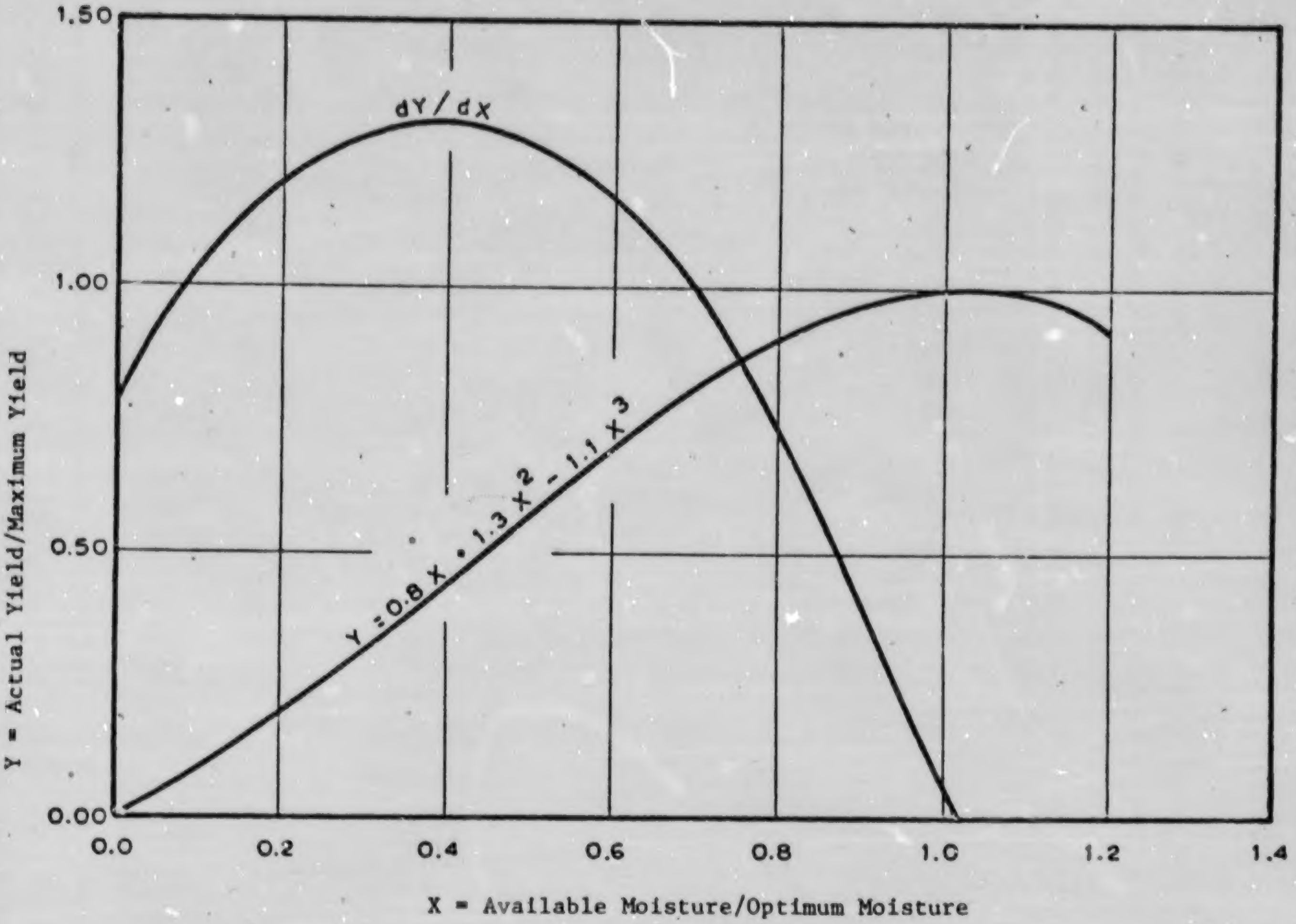

Figure 1. Moisture adequacy and yield function.

MAI = 0.00 to 0.33 very deficient
MAI = 0.34 to 0.67 moderately deficient
MAI = 0.68 to 1.00 somewhat deficient
MAI = 1.01 to 1.33 adequate
MAI = 1.34 and above excessive.

This classification seems applicable for the more favorable soil conditions, and is proposed for general usage. Where the soil moisture storage capacity is adequate for less than one week, the correlation between MAI and forage production probably will be lowered. The minimum values for economic production can then be expected to be correspondingly higher.

Even under the most favorable conditions of soils and moisture distribution, a MAI classification for one month during the growing season of 0.33 or less should be considered as a danger signal. Although the timing of the deficiency is also of importance, the probability of a severely limiting month one year in four should be avoided whenever possible.

MOISTURE AVAILABILITY INDICES FOR MEXICO

Monthly mean values of temperature and precipitation for Mexico were obtained from those published by Wernstedt (1972). Incident solar radiation, RS, as given by Lof, Duffie and Smith (1966) was used. Table 3 gives a summary of climate and moisture availability indices, MAI, for Mexico. For each location, the mean temperature in degrees centigrade is given as MEAN TEMP; the mean incident solar radiation in Langleys per day is shown as MEAN RS; the mean precipitation for the period of record, PM, is given in mm as PRECIP; the dependable precipitation, PD, estimated to approximately equal the 75 percent probability of occurrence, is presented as PREC DEP; potential evapotranspiration, ETP, in mm is shown as POT ET; ETP - PD or the moisture deficit, ETDF, at the 75 percent probability of occurrence is given as PREC DEF; and the moisture availability index, MAI, is listed on the bottom line for each climatic station.

The value of PD and MAI shown under SUM or AV. are calculated from Equation 6a and the definition of MAI. The annual MAI is independent of the monthly values.

CLASSIFICATION OF CLIMATE

Various criteria have been used for classifying climate. One that has been used for Northeast Brazil (1974) is based upon values of MAI. It is proposed that the following criteria also be applied to Mexico:

Criteria	Climatic Classification
All months with MAI in the range of 0.00 to 0.33	Very Arid
One or two months with MAI of 0.34 or above	Arid
Three of four consecutive months with MAI of 0.34 or above	Semi-arid
Five or more consecutive months with MAI of 0.34 or above	Wet-dry

It is proposed that each of the above climatic classifications be evaluated and assigned a maximum carrying capacity for livestock based upon maximum capability for forage production. These maximum values would be associated with the most favorable soil and other conditions.

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TABLE 3 CLIMATE AND MOISTURE AVAILABILITY INDICES FOR MEXICO

ABASOLO YRS 15 ALT 1760 METERS LAT 20 27 LON 101 32

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	SUM OR AV.
MEAN TEMP	15.9	18.0	20.1	22.2	24.3	23.9	22.4	22.0	21.6	20.6	18.2	16.8	20.5
MEAN RS	400.	460.	520.	530.	500.	470.	450.	460.	440.	400.	400.	370.	450.
PRECIP	16.	9.	6.	2.	21.	112.	201.	192.	182.	30.	19.	20.	811.
PREC DEP	1.	0.	0.	0.	5.	68.	131.	125.	117.	11.	3.	4.	610.
POT ET	96.	106.	141.	147.	151.	136.	130.	131.	120.	110.	100.	91.	1460.
PREC DEF	95.	106.	141.	147.	146.	68.	-1.	7.	3.	99.	96.	87.	850.
MAI	.01	.00	.00	.00	.03	.50	1.01	.95	.98	.10	.03	.05	.42

ABASOLO YRS 15 ALT 84 METERS LAT 24 4 LON 98 23

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	SUM OR AV.
MEAN TEMP	18.4	20.3	21.1	26.2	28.6	29.3	29.2	29.8	28.1	25.6	21.0	19.6	24.7
MEAN RS	350.	350.	440.	490.	550.	570.	550.	530.	470.	410.	320.	290.	443.
PRECIP	27.	14.	4.	44.	58.	108.	59.	92.	165.	57.	30.	15.	674.
PREC DEP	9.	0.	0.	21.	31.	66.	31.	55.	105.	30.	11.	1.	486.
POT ET	91.	86.	123.	150.	184.	188.	187.	182.	151.	128.	86.	75.	1631.
PREC DEF	81.	86.	123.	130.	153.	122.	156.	127.	45.	98.	75.	75.	1144.
MAI	.10	.00	.00	.14	.17	.35	.17	.30	.70	.23	.13	.01	.30

ACAPONETA YRS 15 ALT 25 METERS LAT 22 30 LON 105 23

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	SUM OR AV.
MEAN TEMP	20.9	21.9	22.6	24.1	25.8	27.8	27.4	27.6	27.4	27.1	24.7	21.6	24.9
MEAN RS	360.	450.	500.	530.	530.	500.	490.	490.	450.	430.	400.	350.	457.
PRECIP	18.	2.	1.	0.	1.	92.	346.	322.	287.	57.	24.	69.	1218.
PREC DEP	3.	0.	0.	0.	0.	55.	233.	215.	191.	30.	7.	38.	976.
POT ET	99.	116.	145.	154.	166.	159.	160.	160.	142.	139.	118.	99.	1658.
PREC DEF	97.	116.	145.	154.	166.	104.	-73.	-55.	-49.	109.	112.	60.	682.
MAI	.03	.00	.00	.00	.00	.34	1.46	1.34	1.35	.21	.06	.39	.59

ACAPULCO YRS 15 ALT 3 METERS LAT 16 50 LON 99 56

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	SUM OR AV.
MEAN TEMP	25.7	25.7	26.2	26.8	28.2	28.2	28.4	28.3	27.6	27.6	27.0	26.1	27.2
MEAN RS	420.	470.	510.	510.	510.	450.	500.	490.	460.	450.	420.	400.	466.
PRECIP	9.	1.	0.	0.	29.	430.	216.	246.	360.	170.	30.	11.	1504.
PREC DEP	0.	0.	0.	0.	11.	291.	141.	162.	242.	109.	11.	0.	1234.
POT ET	132.	133.	162.	158.	169.	145.	167.	163.	146.	147.	131.	126.	1779.
PREC DEF	132.	133.	162.	158.	159.	-146.	25.	1.	-96.	38.	120.	126.	545.
MAI	.00	.00	.00	.00	.06	2.01	.85	1.00	1.66	.74	.09	.00	.69

ACTOPAN YRS 15 ALT 1989 METERS LAT 20 17 LON 98 58

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	SUM OR AV.
MEAN TEMP	12.7	14.4	16.2	18.0	19.4	19.5	17.8	17.6	17.4	15.6	13.9	13.7	16.3
MEAN RS	350.	450.	510.	530.	500.	470.	450.	470.	450.	390.	360.	350.	440.
PRECIP	10.	6.	13.	16.	39.	66.	67.	65.	84.	50.	20.	5.	439.
PREC DEP	0.	0.	0.	1.	17.	36.	37.	35.	48.	25.	4.	0.	275.
POT ET	76.	93.	124.	131.	133.	118.	114.	119.	109.	93.	79.	78.	1267.
PREC DEF	76.	93.	124.	130.	116.	82.	77.	83.	61.	68.	75.	78.	993.
MAI	.00	.00	.00	.01	.13	.31	.32	.30	.44	.27	.05	.00	.22

AGUA BUENA YRS 15 ALT 350 METERS LAT 21 59 LON 99 24

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	SUM OR AV.
MEAN TEMP	17.3	20.0	21.8	26.0	27.9	28.0	26.7	27.1	26.5	23.9	19.6	17.6	23.5
MEAN RS	350.	450.	510.	540.	510.	470.	450.	480.	450.	400.	360.	350.	443.
PRECIP	58.	42.	23.	22.	124.	240.	471.	258.	445.	217.	63.	37.	2002.
PREC DEP	31.	20.	6.	5.	77.	158.	320.	170.	302.	142.	34.	16.	1682.
POT ET	88.	110.	145.	165.	168.	150.	144.	155.	139.	120.	93.	88.	1566.
PREC DEF	57.	90.	139.	159.	91.	-8.	-176.	-15.	-163.	-22.	59.	72.	-116.
MAI	.35	.18	.04	.03	.46	1.05	2.22	1.10	2.17	1.19	.36	.18	1.07

TABLE 3 CLIMATE AND MOISTURE AVAILABILITY INDICES FOR MEXICO

AGUACALIENTES YRS 15 ALT 1878 METERS LAT 21 53 LON 102 18

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	SUM OR AV.
MEAN TEMP	13.0	14.7	17.4	20.0	22.0	21.3	19.8	19.8	19.2	18.0	15.6	13.8	17.9
MEAN RS	400.	460.	530.	530.	500.	480.	450.	460.	440.	400.	370.	380.	450.
PRECIP	11.	6.	4.	1.	18.	111.	136.	106.	89.	34.	19.	18.	551.
PREC DEP	0.	0.	0.	0.	2.	68.	85.	64.	53.	13.	3.	2.	376.
POT ET	88.	96.	133.	139.	142.	130.	121.	124.	113.	102.	85.	85.	1359.
PREC DEF	88.	96.	133.	139.	140.	62.	36.	59.	60.	89.	82.	83.	983.
MAI	.00	.00	.00	.00	.02	.52	.70	.52	.47	.13	.04	.03	.28

AHOME YRS 15 ALT 39 METERS LAT 25 55 LON 109 11

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	SUM OR AV.
MEAN TEMP	17.5	18.4	20.1	22.8	25.4	29.2	31.7	31.2	30.4	26.7	21.4	18.0	24.4
MEAN RS	350.	400.	500.	490.	580.	600.	570.	500.	500.	490.	400.	300.	473.
PRECIP	3.	5.	5.	1.	1.	7.	49.	80.	77.	27.	12.	58.	324.
PREC DEP	0.	0.	0.	0.	0.	0.	24.	46.	44.	9.	0.	31.	172.
POT ET	88.	93.	136.	138.	180.	197.	204.	177.	168.	157.	109.	77.	1726.
PREC DEF	88.	93.	136.	138.	180.	197.	180.	131.	125.	148.	109.	46.	1554.
MAI	.00	.00	.00	.00	.00	.00	.12	.26	.26	.06	.00	.40	.10

AHUACATLAN YRS 15 ALT 984 METERS LAT 21 5 LON 104 28

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	SUM OR AV.
MEAN TEMP	17.9	18.5	20.2	22.0	24.1	25.5	24.4	24.3	24.4	24.1	20.9	18.2	22.0
MEAN RS	400.	440.	510.	540.	530.	490.	500.	470.	500.	420.	400.	350.	462.
PRECIP	23.	15.	2.	2.	14.	120.	231.	185.	147.	46.	14.	22.	821.
PREC DEP	6.	1.	0.	0.	0.	74.	151.	119.	93.	22.	[illegible]	5.	619.
POT ET	102.	103.	139.	149.	160.	148.	152.	142.	147.	127.	[illegible]	90.	1564.
PREC DEF	95.	102.	139.	149.	160.	74.	0.	23.	54.	104.	107.	85.	945.
MAI	.05	.01	.00	.00	.00	.50	1.00	.84	.63	.18	.00	.06	.40

ALCOZAUCA YRS 15 ALT 1200 METERS LAT 17 18 LON 98 27

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	SUM OR AV.
MEAN TEMP	18.5	20.7	22.3	23.2	23.8	23.6	22.0	21.6	21.5	20.5	19.0	18.8	21.3
MEAN RS	400.	460.	500.	510.	530.	510.	520.	520.	470.	450.	420.	400.	474.
PRECIP	2.	3.	5.	18.	55.	167.	161.	185.	166.	64.	7.	5.	836.
PREC DEP	0.	0.	0.	2.	28.	107.	103.	119.	106.	35.	0.	0.	633.
POT ET	104.	115.	144.	145.	158.	147.	148.	147.	128.	123.	107.	105.	1571.
PREC DEF	104.	115.	144.	143.	130.	40.	46.	28.	22.	89.	107.	105.	938.
MAI	.00	.00	.00	.02	.19	.73	.69	.81	.83	.28	.00	.00	.40

ALTAR YRS 15 ALT 396 METERS LAT 30 44 LON 111 46

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	SUM OR AV.
MEAN TEMP	12.9	15.3	16.5	20.0	24.3	28.7	31.4	30.4	28.9	23.4	17.8	14.2	22.0
MEAN RS	340.	410.	530.	630.	660.	700.	660.	610.	560.	460.	400.	320.	523.
PRECIP	15.	10.	9.	4.	1.	10.	74.	58.	43.	13.	21.	18.	274.
PREC DEP	0.	0.	0.	0.	0.	0.	42.	31.	20.	0.	5.	2.	127.
POT ET	74.	87.	130.	165.	200.	227.	235.	212.	182.	136.	98.	73.	1820.
PREC DEF	74.	87.	130.	165.	200.	227.	193.	182.	162.	136.	94.	71.	1693.
MAI	.00	.00	.00	.00	.00	.00	.18	.14	.11	.00	.05	.03	.07

ALTOTONGA YRS 15 ALT 1186 METERS LAT 19 43 LON 97 15

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	SUM OR AV.
MEAN TEMP	12.0	14.8	16.5	19.1	20.0	19.1	17.6	18.1	17.3	15.8	13.5	12.3	16.3
MEAN RS	360.	450.	480.	500.	500.	450.	440.	460.	440.	370.	350.	330.	427.
PRECIP	91.	33.	33.	47.	103.	215.	181.	190.	342.	295.	226.	160.	1917.
PREC DEP	54.	13.	13.	23.	62.	140.	117.	123.	229.	197.	148.	102.	1605.
POT ET	76.	94.	119.	128.	135.	115.	111.	118.	107.	85.	75.	70.	1236.
PREC DEF	22.	81.	105.	104.	73.	-25.	-6.	-5.	-123.	-108.	-72.	-32.	-369.
MAI	.71	.15	.11	.18	.46	1.22	1.05	1.04	2.15	2.22	1.96	1.45	1.30

TABLE 3 CLIMATE AND MOISTURE AVAILABILITY INDICES FOR MEXICO

ALVARADO YRS 15 ALT 9 METERS LAT 18 47 LON 95 45

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	SUM OR AV.
MEAN TEMP	15.5	17.2	17.2	20.0	20.9	19.8	19.6	19.6	19.7	19.1	17.1	15.8	18.5
MEAN RS	340.	400.	410.	450.	490.	420.	420.	450.	400.	400.	340.	330.	404.
PRECIP	47.	46.	41.	83.	169.	300.	387.	306.	430.	152.	61.	56.	2078.
PREC DEP	23.	23.	18.	48.	109.	200.	261.	204.	291.	97.	33.	29.	1750.
POT ET	81.	90.	102.	118.	136.	109.	112.	120.	104.	106.	82.	79.	1239.
PREC DEF	58.	68.	84.	70.	28.	-91.	-149.	-84.	-187.	9.	49.	49.	-511.
MAT	.28	.25	.18	.41	.80	1.83	2.32	1.70	2.80	.92	.40	.37	1.41

ALVARO OBREGON YRS 15 ALT 1870 METERS LAT 21 0 LON 100 24

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	SUM OR AV.
MEAN TEMP	12.7	14.5	16.9	19.1	20.2	19.1	18.1	17.8	17.4	15.5	14.1	13.6	16.6
MEAN RS	360.	450.	520.	530.	500.	490.	450.	490.	450.	400.	360.	360.	447.
PRECIP	8.	5.	9.	10.	36.	83.	101.	81.	109.	38.	13.	13.	506.
PREC DEP	0.	0.	0.	0.	15.	48.	61.	46.	67.	16.	0.	0.	335.
POT ET	78.	94.	129.	135.	136.	125.	116.	124.	109.	95.	79.	80.	1301.
PREC DEF	78.	94.	129.	135.	121.	77.	55.	78.	43.	79.	79.	80.	966.
MAT	.00	.00	.00	.00	.11	.38	.53	.37	.61	.17	.00	.00	.26

ALVARO OBREGON YRS 15 ALT 1 METERS LAT 18 32 LON 92 39

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	SUM OR AV.
MEAN TEMP	22.9	23.8	24.9	26.3	27.5	27.4	27.2	27.5	27.1	26.0	24.3	23.5	25.7
MEAN RS	340.	410.	470.	440.	450.	440.	400.	460.	370.	400.	390.	330.	408.
PRECIP	59.	70.	42.	28.	62.	176.	140.	131.	189.	309.	133.	127.	1464.
PREC DEP	31.	39.	20.	10.	33.	113.	88.	82.	122.	206.	83.	79.	1198.
POT ET	99.	111.	144.	137.	147.	139.	130.	150.	116.	126.	114.	98.	1511.
PREC DEF	68.	72.	125.	127.	114.	26.	42.	68.	-6.	-80.	31.	19.	313.
MAT	.31	.35	.14	.07	.23	.82	.68	.55	1.05	1.63	.73	.80	.79

AMECA YRS 15 ALT 1235 METERS LAT 20 34 LON 104 4

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	SUM OR AV.
MEAN TEMP	16.9	17.5	19.2	20.5	23.2	24.1	23.9	23.7	23.5	22.4	20.3	18.3	21.1
MEAN RS	390.	450.	510.	520.	520.	480.	470.	470.	450.	440.	400.	350.	456.
PRECIP	26.	5.	3.	7.	35.	169.	208.	195.	119.	57.	20.	37.	880.
PREC DEP	8.	0.	0.	0.	14.	109.	136.	126.	73.	30.	4.	16.	672.
POT ET	97.	102.	135.	138.	153.	140.	141.	146.	129.	127.	106.	90.	1504.
PREC DEF	88.	102.	135.	138.	139.	31.	5.	20.	56.	97.	102.	74.	832.
MAT	.08	.00	.00	.00	.09	.78	.96	.86	.57	.24	.04	.17	.45

APATZINGAN YRS 15 ALT 682 METERS LAT 19 5 LON 102 15

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	SUM OR AV.
MEAN TEMP	25.3	26.6	28.6	30.2	31.6	30.9	28.6	28.0	28.2	28.4	27.2	25.4	28.3
MEAN RS	410.	460.	520.	520.	500.	470.	460.	460.	450.	400.	400.	380.	452.
PRECIP	4.	7.	2.	1.	14.	89.	187.	173.	168.	46.	8.	16.	716.
PREC DEP	0.	0.	0.	0.	0.	52.	121.	111.	108.	23.	0.	1.	524.
POT ET	127.	133.	174.	175.	179.	160.	154.	152.	145.	133.	126.	118.	1775.
PREC DEF	127.	133.	174.	175.	179.	108.	33.	41.	37.	111.	126.	117.	1251.
MAT	.00	.00	.00	.00	.00	.33	.79	.73	.75	.17	.00	.01	.30

APIZACO YRS 15 ALT 2407 METERS LAT 19 25 LON 98 8

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	SUM OR AV.
MEAN TEMP	10.7	12.0	14.2	14.8	16.5	15.6	14.6	14.9	14.9	14.1	11.8	11.7	13.8
MEAN RS	360.	450.	500.	500.	490.	450.	440.	450.	440.	390.	360.	350.	432.
PRECIP	8.	2.	7.	26.	120.	150.	229.	161.	184.	51.	13.	10.	960.
PREC DEP	0.	0.	0.	8.	74.	95.	150.	103.	119.	26.	0.	0.	744.
POT ET	73.	86.	114.	112.	120.	104.	102.	105.	99.	89.	73.	73.	1149.
PREC DEF	73.	86.	114.	104.	46.	8.	-48.	2.	-20.	63.	73.	73.	406.
MAT	.00	.00	.00	.07	.61	.92	1.47	.99	1.20	.29	.00	.00	.65

TABLE 3 CLIMATE AND MOISTURE AVAILABILITY INDICES FOR MEXICO

ATOYAC YRS 15 ALT 200 METERS LAT 1[illegible] 17 LON 100 26

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	SUM OR AV.
MEAN TEMP	28.5	28.5	29.0	29.7	31.2	30.2	30.6	30.6	29.4	29.9	29.6	29.3	29.7
MEAN RS	410.	460.	500.	510.	530.	510.	520.	520.	470.	450.	420.	400.	475.
PRECIP	12.	0.	0.	0.	38.	263.	163.	194.	350.	153.	56.	14.	1249.
PREC DEP	0.	0.	0.	0.	17.	174.	104.	125.	239.	97.	29.	0.	1004.
POT ET	137.	139.	169.	169.	188.	171.	182.	182.	155.	155.	139.	136.	1923.
PREC DEF	137.	139.	169.	169.	171.	-3.	78.	56.	-84.	58.	110.	136.	919.
MAI	.00	.00	.00	.00	.09	1.02	.57	.69	1.54	.63	.21	.00	.52

ATZALAN YRS 15 ALT 1320 METERS LAT 19 48 LON 97 13

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	SUM OR AV.
MEAN TEMP	12.1	13.4	15.1	16.9	18.3	17.7	16.9	17.0	16.4	15.1	12.7	11.8	15.3
MEAN RS	370.	440.	500.	500.	480.	450.	440.	450.	430.	390.	350.	340.	428.
PRECIP	87.	57.	67.	73.	99.	258.	277.	232.	337.	348.	166.	69.	2067.
PREC DEP	51.	30.	37.	41.	59.	171.	184.	153.	226.	234.	106.	35.	1741.
POT ET	79.	88.	117.	120.	124.	110.	109.	112.	102.	91.	74.	71.	1197.
PREC DEF	27.	58.	80.	78.	64.	-60.	-75.	-41.	-124.	-142.	-33.	37.	-544.
MAI	.65	.34	.32	.35	.48	1.55	1.69	1.37	2.23	2.56	1.45	.49	1.45

AURORA YRS 15 ALT 254 METERS LAT 15 12 LON 92 25

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	SUM OR AV.
MEAN TEMP	23.9	27.0	28.7	28.1	28.3	27.1	26.7	27.2	26.9	27.0	26.9	26.1	27.0
MEAN RS	400.	460.	500.	430.	450.	390.	410.	400.	390.	370.	450.	400.	422.
PRECIP	34.	21.	50.	126.	457.	906.	599.	727.	797.	531.	134.	51.	4433.
PREC DEP	14.	5.	25.	78.	310.	624.	409.	499.	548.	362.	84.	26.	3069.
POT ET	120.	134.	166.	144.	150.	122.	131.	130.	121.	119.	140.	126.	1604.
PREC DEF	106.	129.	141.	66.	-160.	-502.	-278.	-369.	-427.	-243.	56.	101.	-2265.
MAI	.11	.03	.15	.54	2.07	5.11	3.12	3.84	4.51	3.03	.60	.20	2.41

BADIRAGUATO YRS 15 ALT 170 METERS LAT 25 22 LON 107 29

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	SUM OR AV.
MEAN TEMP	18.0	19.1	21.0	23.9	25.8	30.0	28.3	28.1	28.3	26.8	22.6	19.0	24.2
MEAN RS	360.	400.	500.	550.	550.	600.	550.	500.	500.	470.	400.	340.	477.
PRECIP	14.	20.	7.	0.	5.	49.	310.	263.	167.	61.	12.	76.	983.
PREC DEP	0.	4.	0.	0.	0.	24.	207.	174.	107.	33.	0.	43.	764.
POT ET	92.	95.	139.	159.	173.	201.	183.	166.	161.	151.	112.	89.	1720.
PREC DEF	92.	91.	139.	159.	173.	177.	-24.	-8.	54.	118.	112.	46.	956.
MAI	.00	.04	.00	.00	.00	.12	1.13	1.05	.66	.22	.00	.48	.44

BELLAVISTA YRS 15 ALT 292 METERS LAT 32 1 LON 116 37

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	SUM OR AV.
MEAN TEMP	11.6	12.9	13.9	15.1	17.5	19.5	22.5	23.2	20.7	17.9	15.9	12.7	16.9
MEAN RS	300.	390.	510.	560.	610.	700.	650.	610.	540.	410.	350.	300.	494.
PRECIP	52.	75.	40.	41.	11.	2.	1.	1.	4.	21.	21.	81.	349.
PREC DEP	26.	42.	18.	19.	0.	0.	0.	0.	0.	5.	5.	46.	194.
POT ET	63.	77.	115.	127.	154.	181.	188.	180.	144.	104.	81.	64.	1477.
PREC DEF	36.	34.	97.	108.	154.	181.	188.	180.	144.	100.	77.	18.	1283.
MAI	.42	.55	.16	.15	.00	.00	.00	.00	.00	.04	.06	.73	.13

BOLFO EL YRS 15 ALT [illegible] METERS LAT 27 19 LON 112 20

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	SUM OR AV.
MEAN TEMP	16.1	18.0	20.0	22.7	26.1	29.2	31.4	31.5	30.2	26.5	21.3	17.6	24.2
MEAN RS	340.	380.	500.	570.	630.	660.	640.	560.	550.	480.	400.	320.	502.
PRECIP	2.	3.	0.	1.	2.	0.	5.	16.	50.	10.	7.	28.	124.
PREC DEP	0.	0.	0.	0.	0.	0.	0.	1.	25.	0.	0.	10.	0.
POT ET	82.	88.	135.	160.	199.	217.	228.	200.	185.	153.	108.	81.	1836.
PREC DEF	82.	88.	135.	160.	199.	217.	228.	198.	160.	153.	108.	71.	1836.
MAI	.00	.00	.00	.00	.00	.00	.00	.01	.13	.00	.00	.12	.00

TABLE 3 CLIMATE AND MOISTURE AVAILABILITY INDICES FOR MEXICO

BURRO EL YRS 15 ALT 0 METERS LAT 29 13 LON 101 55

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	SUM OR AV.
MEAN TEMP	12.9	16.0	18.8	22.4	24.9	27.4	26.5	26.7	25.9	23.0	[illegible]	14.1	21.3
MEAN RS	410.	380.	510.	560.	580.	630.	630.	570.	520.	400.	[illegible]	[illegible]	491.
PRECIP	8.	3.	1.	6.	14.	16.	39.	16.	24.	9.	[illegible]	10.	151.
PREC DEP	0.	0.	0.	0.	0.	1.	18.	1.	7.	0.	0.	0.	16.
POT ET	89.	83.	133.	156.	178.	199.	201.	193.	158.	117.	73.	64.	1634.
PREC DEF	89.	83.	133.	156.	178.	197.	183.	182.	151.	117.	73.	64.	1618.
MAI	.00	.00	.00	.00	.00	.01	.09	.01	.04	.00	.00	.00	.01

BUSTILLOS YRS 15 ALT 2042 METERS LAT 28 30 LON 106 39

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	SUM OR AV.
MEAN TEMP	4.6	5.7	9.6	16.4	17.9	19.6	19.5	18.4	17.3	14.7	9.1	4.4	13.1
MEAN RS	350.	450.	520.	600.	630.	640.	600.	570.	560.	450.	380.	320.	506.
PRECIP	14.	0.	5.	0.	16.	15.	89.	148.	35.	34.	18.	9.	383.
PREC DEP	0.	0.	0.	0.	1.	0.	52.	94.	14.	14.	3.	0.	224.
POT ET	55.	68.	101.	142.	160.	166.	160.	147.	136.	104.	70.	50.	1359.
PREC DEF	55.	68.	101.	142.	159.	165.	108.	54.	121.	90.	68.	50.	1135.
MAI	.00	.00	.00	.00	.01	.00	.33	.64	.10	.13	.04	.00	.16

CABO CORRIENTES YRS 15 ALT 85 METERS LAT 20 24 LON 105 43

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	SUM OR AV.
MEAN TEMP	23.2	22.9	22.7	23.9	25.4	26.7	28.1	27.9	27.5	27.8	26.1	23.8	25.5
MEAN RS	390.	440.	500.	530.	520.	500.	510.	500.	460.	450.	400.	340.	462.
PRECIP	20.	29.	1.	0.	2.	57.	145.	272.	307.	91.	15.	13.	954.
PREC DEP	4.	11.	0.	0.	0.	30.	92.	180.	205.	54.	1.	0.	739.
POT ET	115.	116.	145.	154.	162.	155.	169.	165.	145.	148.	122.	102.	1698.
PREC DEF	111.	105.	145.	154.	162.	125.	77.	-16.	-60.	94.	122.	102.	959.
MAI	.03	.09	.00	.00	.00	.19	.54	1.10	1.41	.36	.01	.00	.43

CALAYA YRS 15 ALT 1753 METERS LAT 20 32 LON 100 49

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	SUM OR AV.
MEAN TEMP	14.5	16.8	20.0	23.3	25.4	24.6	23.6	22.8	21.8	19.5	16.9	15.1	20.4
MEAN RS	350.	460.	520.	520.	500.	460.	450.	460.	440.	390.	300.	360.	441.
PRECIP	8.	9.	6.	10.	31.	101.	190.	135.	150.	36.	14.	12.	663.
PREC DEP	0.	0.	0.	0.	12.	61.	95.	85.	95.	15.	0.	0.	477.
POT ET	81.	103.	141.	148.	155.	136.	134.	134.	121.	104.	91.	84.	1432.
PREC DEF	81.	103.	141.	148.	144.	75.	39.	49.	26.	89.	91.	84.	955.
MAI	.00	.00	.00	.00	.08	.45	.71	.63	.78	.15	.00	.00	.33

CALLES PRESA YRS 15 ALT 2025 METERS LAT 22 6 LON 102 25

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	SUM OR AV.
MEAN TEMP	12.1	13.5	15.4	18.1	20.4	20.9	19.3	19.3	18.9	17.1	14.7	13.3	16.9
MEAN RS	380.	470.	520.	530.	500.	490.	450.	470.	450.	400.	380.	360.	450.
PRECIP	20.	8.	3.	2.	26.	74.	152.	109.	104.	29.	24.	7.	558.
PREC DEP	4.	0.	0.	0.	8.	42.	97.	66.	63.	11.	7.	0.	382.
POT ET	81.	95.	123.	132.	137.	131.	119.	125.	114.	100.	84.	80.	1319.
PREC DEF	77.	95.	123.	132.	129.	90.	23.	58.	52.	89.	77.	80.	937.
MAI	.05	.00	.00	.00	.06	.32	.81	.53	.55	.11	.08	.00	.29

CAMARGO YRS 15 ALT 1653 METERS LAT 27 42 LON 105 10

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	SUM OR AV.
MEAN TEMP	11.8	14.4	16.8	20.4	24.8	29.1	28.4	26.8	25.6	21.7	15.9	11.6	20.6
MEAN RS	360.	450.	520.	590.	600.	630.	600.	560.	550.	450.	370.	380.	505.
PRECIP	13.	4.	4.	5.	8.	25.	80.	59.	55.	31.	13.	21.	317.
PREC DEP	0.	0.	0.	0.	0.	7.	46.	31.	28.	12.	0.	4.	165.
POT ET	76.	93.	128.	156.	184.	207.	200.	180.	166.	128.	96.	79.	1682.
PREC DEF	76.	93.	128.	156.	184.	199.	154.	148.	138.	116.	86.	75.	1517.
MAI	.00	.00	.00	.00	.00	.04	.23	.17	.17	.09	.00	.06	.10

TABLE 3 CLIMATE AND MOISTURE AVAILABILITY INDICES FOR MEXICO

CAMARGO   YRS 15 ALT 67 METERS LAT 26 19 LON 98 50

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	SUM OR AV.
MEAN TEMP	15.8	18.8	22.1	26.0	28.4	30.0	31.0	31.7	29.3	25.4	20.7	15.6	24.6
MEAN RS	290.	400.	440.	480.	550.	600.	610.	550.	480.	420.	300.	270.	449.
PRECIP	31.	31.	34.	20.	61.	85.	41.	23.	115.	58.	43.	57.	600.
PREC DEP	12.	12.	13.	4.	33.	49.	19.	6.	70.	30.	20.	30.	420.
POT ET	69.	94.	126.	146.	183.	201.	215.	197.	158.	132.	80.	64.	1667.
PREC DEF	57.	82.	113.	142.	150.	151.	196.	191.	88.	101.	60.	34.	1247.
MAI	.17	.13	.11	.03	.18	.25	.09	.03	.45	.23	.25	.47	.25

CAMARON   YRS 15 ALT 186 METERS LAT 27 18 LON 100 4

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	SUM OR AV.
MEAN TEMP	12.8	15.7	18.4	23.4	26.4	30.0	30.3	30.9	28.0	24.1	16.6	12.6	22.4
MEAN RS	300.	390.	440.	500.	550.	600.	630.	560.	490.	420.	400.	270.	462.
PRECIP	36.	27.	19.	33.	121.	42.	22.	32.	87.	31.	26.	20.	496.
PREC DEP	15.	9.	3.	13.	75.	20.	5.	12.	51.	12.	8.	4.	326.
POT ET	65.	84.	114.	143.	175.	201.	219.	197.	157.	127.	95.	58.	1639.
PREC DEF	50.	75.	111.	130.	100.	181.	213.	185.	106.	115.	87.	55.	1308.
MAI	.23	.11	.03	.09	.43	.10	.02	.06	.33	.09	.09	.07	.20

CAMPECHE   YRS 15 ALT 25 METERS LAT 19 57 LON 90 32

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	SUM OR AV.
MEAN TEMP	22.6	23.6	25.0	26.8	27.7	27.5	26.9	27.1	27.2	26.3	24.4	23.4	25.7
MEAN RS	460.	420.	500.	490.	470.	490.	440.	490.	430.	400.	390.	340.	436.
PRECIP	18.	10.	13.	6.	44.	154.	175.	169.	144.	87.	34.	35.	890.
PREC DEP	2.	0.	0.	0.	21.	98.	113.	109.	91.	51.	13.	14.	681.
POT ET	116.	113.	154.	152.	154.	155.	142.	159.	126.	127.	114.	100.	1612.
PREC DEF	114.	113.	154.	152.	133.	57.	29.	50.	35.	76.	101.	86.	931.
MAI	.02	.00	.00	.00	.14	.63	.79	.68	.72	.40	.12	.14	.42

CANANEA   YRS 15 ALT 1606 METERS LAT 30 59 LON 110 18

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	SUM OR AV.
MEAN TEMP	6.6	7.4	9.4	12.9	17.8	24.5	23.4	22.6	20.5	16.8	11.4	6.2	15.0
MEAN RS	340.	420.	530.	640.	670.	700.	660.	610.	570.	480.	400.	320.	528.
PRECIP	27.	50.	21.	16.	17.	27.	147.	113.	80.	33.	38.	56.	623.
PREC DEP	9.	25.	5.	1.	2.	9.	93.	69.	46.	13.	16.	29.	441.
POT ET	59.	68.	102.	135.	170.	206.	197.	177.	151.	118.	80.	54.	1518.
PREC DEF	50.	43.	97.	134.	168.	197.	104.	108.	106.	105.	64.	25.	1077.
MAI	.15	.37	.05	.01	.01	.04	.47	.39	.30	.11	.21	.54	.29

CARBO   YRS 15 ALT 464 METERS LAT 29 43 LON 110 58

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	SUM OR AV.
MEAN TEMP	15.8	16.2	17.2	20.5	23.9	27.4	29.0	29.2	28.4	24.2	20.3	14.6	22.2
MEAN RS	340.	410.	520.	620.	660.	690.	650.	600.	560.	490.	400.	320.	522.
PRECIP	1.	1.	8.	4.	6.	3.	122.	96.	44.	8.	6.	71.	361.
PREC DEP	0.	0.	0.	0.	0.	0.	76.	50.	21.	0.	0.	40.	205.
POT ET	81.	90.	130.	165.	198.	218.	220.	204.	181.	148.	106.	74.	1813.
PREC DEF	81.	90.	130.	165.	198.	218.	144.	153.	159.	148.	106.	74.	1608.
MAI	.00	.00	.00	.00	.00	.00	.34	.25	.12	.00	.00	.54	.11

CARMEN CIUDAD   YRS 15 ALT 3 METERS LAT 18 38 LON 91 45

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	SUM OR AV.
MEAN TEMP	23.0	24.3	25.7	27.0	28.0	27.4	27.3	27.4	27.2	25.7	23.9	23.4	25.8
MEAN RS	340.	430.	450.	450.	460.	490.	400.	460.	360.	400.	390.	340.	413.
PRECIP	102.	42.	51.	38.	113.	172.	168.	212.	230.	278.	124.	152.	1683.
PREC DEP	61.	19.	26.	17.	69.	110.	109.	138.	151.	185.	77.	86.	1394.
POT ET	100.	117.	140.	140.	152.	151.	130.	150.	113.	125.	113.	100.	1532.
PREC DEF	38.	98.	114.	124.	83.	41.	22.	11.	-38.	-59.	36.	4.	138.
MAI	.62	.16	.19	.12	.45	.73	.83	.92	1.33	1.47	.68	.96	.91

TABLE 3 CLIMATE AND MOISTURE AVAILABILITY INDICES FOR MEXICO

CARMEN YRS 15 ALT 0 METERS LAT 24 5 LON 99 10

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	SUM OR AV.
MEAN TEMP	15.7	19.9	21.9	24.6	26.5	28.3	28.2	28.3	26.5	23.8	18.9	15.6	23.1
MEAN RS	300.	460.	450.	470.	540.	460.	590.	540.	480.	410.	320.	280.	438.
PRECIP	9.	15.	16.	66.	102.	117.	61.	29.	157.	62.	19.	10.	661.
PREC DEP	0.	1.	1.	36.	61.	72.	33.	11.	97.	34.	4.	0.	475.
POT ET	72.	95.	128.	139.	172.	148.	196.	179.	148.	123.	81.	69.	1550.
PREC DEF	72.	94.	127.	102.	111.	76.	163.	169.	51.	89.	78.	69.	1075.
MAI	.00	.01	.01	.26	.36	.49	.17	.06	.65	.28	.04	.00	.31

CARRILLO YRS 19 ALT 1102 METERS LAT 26 52 LON 103 57

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	SUM OR AV.
MEAN TEMP	11.5	13.2	16.2	19.6	22.5	25.2	24.1	24.4	22.8	19.2	15.0	11.7	18.8
MEAN RS	330.	460.	520.	550.	550.	610.	600.	560.	500.	420.	360.	300.	480.
PRECIP	5.	5.	10.	4.	7.	40.	52.	56.	73.	11.	5.	21.	289.
PREC DEP	0.	0.	0.	0.	0.	18.	26.	29.	41.	0.	0.	5.	140.
POT ET	69.	92.	126.	142.	159.	183.	181.	170.	141.	111.	81.	63.	1517.
PREC DEF	69.	92.	126.	142.	159.	165.	155.	141.	100.	111.	81.	58.	1377.
MAI	.00	.00	.00	.00	.00	.10	.14	.17	.29	.00	.00	.08	.09

CASAS GRANDES YRS 15 ALT 1470 METERS LAT 30 22 LON 104 59

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	SUM OR AV.
MEAN TEMP	7.6	10.1	13.2	14.9	20.2	25.4	25.7	24.3	21.8	16.9	11.0	7.1	16.5
MEAN RS	330.	430.	530.	650.	630.	640.	650.	590.	550.	440.	350.	300.	507.
PRECIP	9.	16.	7.	10.	13.	21.	66.	96.	53.	34.	19.	22.	357.
PREC DEP	0.	1.	0.	0.	0.	5.	36.	50.	27.	14.	3.	5.	201.
POT ET	59.	77.	117.	146.	172.	193.	204.	178.	151.	109.	69.	53.	1528.
PREC DEF	59.	75.	117.	146.	172.	188.	168.	128.	124.	95.	66.	48.	1327.
MAI	.00	.02	.00	.00	.00	.03	.18	.28	.18	.13	.04	.10	.13

CEDRAL YRS 15 ALT 0 METERS LAT 23 49 LON 100 48

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	SUM OR AV.
MEAN TEMP	11.5	13.8	16.9	19.5	21.6	21.6	20.6	20.8	20.4	19.0	14.2	12.7	17.8
MEAN RS	350.	440.	500.	540.	540.	560.	500.	520.	470.	400.	350.	350.	460.
PRECIP	25.	9.	5.	4.	57.	40.	77.	38.	35.	28.	28.	5.	350.
PREC DEP	8.	0.	0.	0.	30.	18.	44.	17.	14.	9.	10.	0.	195.
POT ET	73.	89.	122.	139.	152.	153.	138.	144.	124.	102.	77.	76.	1390.
PREC DEF	65.	89.	122.	139.	122.	135.	94.	127.	110.	93.	67.	76.	1195.
MAI	.11	.00	.00	.00	.20	.12	.32	.12	.12	.09	.13	.00	.14

CERRITOS YRS 15 ALT 1157 METERS LAT 22 25 LON 160 17

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	SUM OR AV.
MEAN TEMP	17.4	20.9	23.3	26.6	28.2	27.4	26.3	27.2	26.7	24.3	20.7	17.8	23.9
MEAN RS	380.	450.	500.	530.	500.	550.	480.	500.	460.	400.	360.	350.	455.
PRECIP	21.	8.	18.	17.	55.	97.	78.	65.	97.	53.	25.	14.	549.
PREC DEP	4.	0.	3.	2.	29.	58.	45.	35.	58.	27.	8.	0.	374.
POT ET	95.	113.	147.	164.	166.	173.	152.	162.	141.	121.	96.	89.	1671.
PREC DEF	91.	113.	145.	162.	137.	115.	109.	127.	83.	94.	88.	89.	1296.
MAI	.05	.00	.02	.01	.17	.33	.29	.22	.41	.22	.08	.00	.27

CINTALAPA YRS 15 ALT 554 METERS LAT 16 42 LON 93 45

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	SUM OR AV.
MEAN TEMP	19.9	21.0	23.1	24.9	26.4	24.9	24.8	24.9	24.3	22.9	21.2	20.6	23.2
MEAN RS	350.	460.	500.	410.	450.	390.	410.	410.	350.	350.	400.	350.	402.
PRECIP	5.	5.	4.	3.	69.	207.	154.	140.	161.	84.	9.	4.	845.
PREC DEP	0.	0.	0.	0.	38.	135.	98.	88.	103.	49.	0.	0.	640.
POT ET	94.	115.	147.	122.	143.	116.	125.	126.	102.	102.	108.	96.	1398.
PREC DEF	94.	115.	147.	122.	105.	-19.	27.	38.	-0.	53.	108.	96.	757.
MAI	.00	.00	.00	.00	.27	1.16	.78	.70	1.00	.48	.00	.00	.46

TABLE 3 CLIMATE AND MOISTURE AVAILABILITY INDICES FOR MEXICO

COLIMA YRS 15 ALT 493 METERS LAT 19 14 LON 103 45

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	SUM OR AV.
MEAN TEMP	22.4	22.6	23.4	25.0	26.2	26.4	25.9	25.6	25.1	25.4	24.3	22.9	24.6
MEAN RS	340.	450.	500.	530.	510.	480.	500.	460.	460.	400.	410.	380.	452.
PRECIP	13.	8.	0.	0.	8.	144.	192.	181.	194.	79.	24.	35.	877.
PREC DEP	0.	0.	0.	0.	0.	90.	125.	117.	126.	45.	7.	14.	670.
POT ET	98.	118.	149.	158.	162.	148.	157.	144.	137.	124.	120.	111.	1624.
PREC DEF	98.	118.	148.	158.	162.	57.	33.	27.	12.	79.	113.	97.	955.
MAI	.00	.00	.00	.00	.00	.61	.79	.81	.92	.37	.05	.13	.41

COMITAN YRS 15 ALT 1635 METERS LAT 16 15 LON 92 7

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	SUM OR AV.
MEAN TEMP	16.0	17.0	18.3	19.5	19.6	18.9	18.6	18.7	18.6	17.8	16.6	16.6	18.0
MEAN RS	360.	450.	500.	410.	450.	390.	410.	400.	350.	350.	410.	350.	402.
PRECIP	13.	10.	8.	34.	141.	214.	121.	114.	202.	117.	19.	13.	1004.
PREC DEP	0.	0.	0.	13.	89.	140.	74.	70.	131.	72.	3.	0.	784.
POT ET	87.	101.	129.	106.	120.	99.	107.	104.	88.	89.	97.	86.	1213.
PREC DEF	87.	101.	129.	92.	32.	-41.	32.	35.	-43.	17.	94.	86.	430.
MAI	.00	.00	.00	.13	.74	1.41	.70	.67	1.49	.81	.03	.00	.65

COMONFORT YRS 15 ALT 1793 METERS LAT 20 44 LON 100 45

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	SUM OR AV.
MEAN TEMP	15.4	16.8	19.3	20.8	22.8	23.1	22.0	21.9	21.0	19.9	17.6	16.6	19.8
MEAN RS	350.	460.	520.	520.	500.	460.	450.	460.	440.	390.	380.	360.	441.
PRECIP	15.	7.	4.	14.	40.	113.	172.	171.	129.	43.	11.	15.	734.
PREC DEP	1.	0.	0.	0.	18.	69.	111.	110.	80.	20.	0.	1.	541.
POT ET	83.	103.	138.	139.	146.	131.	128.	131.	118.	105.	93.	88.	1403.
PREC DEF	82.	103.	139.	139.	128.	62.	18.	21.	38.	85.	93.	88.	862.
MAI	.01	.00	.00	.00	.12	.53	.86	.84	.68	.19	.00	.01	.39

CONCORDIA YRS 15 ALT 1104 METERS LAT 25 47 LON 103 7

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	SUM OR AV.
MEAN TEMP	12.8	15.9	18.0	21.4	24.7	26.1	26.1	26.4	24.7	22.0	16.2	12.4	20.6
MEAN RS	350.	460.	520.	550.	550.	610.	580.	540.	490.	420.	360.	340.	481.
PRECIP	11.	5.	2.	3.	7.	16.	33.	19.	41.	20.	13.	21.	190.
PREC DEP	0.	0.	0.	0.	0.	1.	13.	3.	19.	4.	0.	5.	51.
POT ET	76.	100.	133.	149.	168.	187.	183.	172.	145.	120.	85.	73.	1590.
PREC DEF	76.	100.	133.	149.	168.	185.	170.	169.	126.	116.	85.	68.	1539.
MAI	.00	.00	.00	.00	.00	.01	.07	.02	.13	.03	.00	.07	.03

COPAINALA YRS 15 ALT 450 METERS LAT 17 5 LON 93 10

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	SUM OR AV.
MEAN TEMP	19.4	20.4	21.9	24.1	25.3	24.1	23.5	23.7	23.8	22.3	20.2	19.5	22.3
MEAN RS	340.	450.	460.	420.	450.	400.	420.	440.	350.	360.	400.	340.	402.
PRECIP	19.	14.	19.	17.	76.	199.	133.	131.	190.	193.	26.	40.	1047.
PREC DEP	4.	0.	3.	2.	43.	130.	83.	81.	123.	119.	8.	18.	822.
POT ET	90.	111.	131.	122.	140.	117.	125.	131.	101.	104.	105.	91.	1368.
PREC DEF	87.	111.	129.	171.	97.	-13.	42.	50.	-22.	-15.	97.	73.	546.
MAI	.04	.00	.02	.01	.31	1.11	.66	.62	1.22	1.14	.08	.20	.60

COQUIMATLAN YRS 15 ALT 318 METERS LAT 19 12 LON 103 49

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	SUM OR AV.
MEAN TEMP	22.6	22.6	23.8	25.1	26.0	26.7	25.9	26.0	25.1	25.1	24.2	23.2	24.7
MEAN RS	410.	450.	510.	530.	530.	490.	470.	460.	460.	430.	410.	380.	461.
PRECIP	11.	6.	0.	0.	9.	130.	162.	165.	212.	92.	22.	50.	859.
PREC DEP	0.	0.	0.	0.	0.	81.	103.	106.	139.	55.	5.	25.	653.
POT ET	119.	118.	152.	158.	167.	152.	148.	145.	137.	133.	120.	112.	1661.
PREC DEF	119.	118.	157.	158.	167.	71.	45.	39.	-1.	78.	115.	87.	1008.
MAI	.00	.00	.00	.00	.00	.53	.70	.73	1.01	.41	.04	.22	.39

TABLE 3 CLIMATE AND MOISTURE AVAILABILITY INDICES FOR MEXICO

COSALA YRS 15 ALT 450 METERS LAT 24 23 LON 106 41

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	SUM OR AV.
MEAN TEMP	18.0	19.3	20.5	23.4	25.9	28.4	27.7	27.2	28.4	25.9	22.0	18.7	23.8
MEAN RS	350.	440.	510.	540.	550.	560.	500.	500.	480.	440.	400.	350.	467.
PRECIP	15.	20.	3.	0.	9.	80.	292.	223.	190.	47.	8.	52.	939.
PREC DEP	0.	4.	0.	0.	0.	46.	194.	146.	123.	23.	0.	26.	725.
POT ET	89.	105.	140.	154.	173.	181.	164.	162.	155.	138.	111.	89.	1662.
PREC DEF	89.	102.	140.	154.	173.	135.	-30.	16.	31.	116.	111.	63.	936.
MAI	.01	.04	.00	.00	.00	.25	1.18	.90	.80	.17	.00	.30	.44

COTIJA YRS 15 ALT 1520 METERS LAT 19 45 LON 102 39

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	SUM OR AV.
MEAN TEMP	16.9	18.0	18.5	19.5	20.9	20.8	20.4	19.6	19.4	18.6	17.5	16.4	18.9
MEAN RS	410.	470.	510.	520.	500.	470.	450.	500.	450.	410.	410.	300.	450.
PRECIP	28.	15.	3.	2.	22.	115.	136.	155.	126.	41.	20.	30.	694.
PREC DEP	10.	1.	0.	0.	5.	71.	85.	99.	78.	19.	4.	11.	504.
POT ET	102.	108.	132.	134.	139.	126.	123.	134.	116.	107.	100.	73.	1393.
PREC DEF	92.	108.	132.	134.	133.	55.	38.	35.	38.	88.	96.	62.	889.
MAI	.10	.01	.00	.00	.04	.56	.69	.74	.68	.19	.04	.15	.36

COZUMEL YRS 15 ALT 3 METERS LAT 20 31 LON 86 57

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	SUM OR AV.
MEAN TEMP	23.0	23.2	24.3	25.9	26.8	26.8	27.1	27.2	26.7	26.1	24.3	23.2	25.4
MEAN RS	360.	450.	530.	550.	500.	510.	540.	530.	500.	400.	410.	350.	469.
PRECIP	83.	31.	57.	54.	177.	177.	76.	127.	213.	301.	121.	85.	1502.
PREC DEP	48.	12.	30.	28.	114.	114.	43.	79.	139.	201.	75.	50.	1231.
POT ET	105.	120.	160.	167.	160.	158.	175.	172.	155.	126.	120.	103.	1723.
PREC DEF	57.	108.	131.	140.	47.	45.	132.	93.	16.	-75.	45.	53.	492.
MAI	.46	.10	.18	.16	.71	.72	.25	.46	.90	1.59	.62	.48	.71

CUATROCIENEGAS YRS 15 ALT 742 METERS LAT 26 59 LON 102 4

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	SUM OR AV.
MEAN TEMP	13.6	17.4	20.0	24.2	27.0	29.2	29.3	29.4	27.9	24.1	19.0	14.6	23.0
MEAN RS	340.	440.	480.	550.	550.	610.	560.	550.	500.	420.	340.	290.	469.
PRECIP	7.	6.	1.	3.	17.	15.	13.	13.	18.	16.	8.	17.	134.
PREC DEP	0.	0.	0.	0.	2.	1.	0.	0.	3.	1.	0.	2.	0.
POT ET	76.	100.	130.	161.	177.	201.	190.	188.	159.	127.	87.	67.	1662.
PREC DEF	76.	100.	130.	161.	175.	200.	190.	188.	157.	125.	87.	65.	1661.
MAI	.00	.00	.00	.00	.01	.00	.00	.00	.02	.01	.00	.02	.00

CUAUTLA YRS 15 ALT 1290 METERS LAT 18 49 LON 98 57

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	SUM OR AV.
MEAN TEMP	20.9	21.1	22.9	23.8	24.8	22.9	22.6	23.3	21.5	21.7	21.0	20.5	22.2
MEAN RS	350.	440.	490.	460.	460.	450.	400.	470.	360.	350.	390.	340.	413.
PRECIP	0.	3.	1.	7.	43.	87.	140.	119.	180.	53.	7.	0.	640.
PREC DEP	0.	0.	0.	0.	20.	51.	88.	73.	116.	27.	0.	0.	456.
POT ET	97.	111.	143.	133.	141.	127.	116.	139.	98.	99.	105.	93.	1402.
PREC DEF	97.	111.	143.	133.	121.	76.	28.	65.	-18.	72.	105.	93.	946.
MAI	.00	.00	.00	.00	.14	.40	.76	.53	1.18	.27	.00	.00	.33

CUERNAVACA YRS 15 ALT 1538 METERS LAT 18 55 LON 99 14

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	SUM OR AV.
MEAN TEMP	18.4	19.4	21.0	22.5	23.7	21.3	20.2	20.0	19.8	19.8	19.4	19.1	20.3
MEAN RS	400.	470.	520.	510.	500.	440.	450.	450.	440.	390.	380.	360.	442.
PRECIP	3.	5.	7.	9.	53.	195.	217.	217.	245.	78.	8.	3.	1039.
PREC DEP	0.	0.	0.	0.	27.	127.	142.	142.	161.	44.	0.	0.	815.
POT ET	103.	113.	145.	143.	147.	119.	123.	122.	114.	105.	98.	95.	1426.
PREC DEF	103.	113.	145.	143.	120.	-7.	-19.	-20.	-47.	60.	98.	95.	611.
MAI	.00	.00	.00	.00	.18	1.06	1.16	1.17	1.41	.42	.00	.00	.57

TABLE 3 CLIMATIC AND MOISTURE AVAILABILITY INDICES FOR MEXICO

CUICATLAN YRS 15 ALT 595 METERS LAT 17 48 LON 96 58

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	SUM OR AV.
MEAN TEMP	23.1	22.7	24.3	26.4	26.5	25.6	25.0	25.7	24.2	23.4	23.4	23.8	24.5
MEAN RS	350.	460.	490.	460.	450.	400.	450.	450.	400.	380.	350.	350.	416.
PRECIP	0.	0.	2.	17.	10.	117.	42.	33.	62.	8.	0.	10.	298.
PREC DEP	0.	0.	0.	2.	0.	72.	19.	13.	33.	0.	0.	0.	149.
POT ET	103.	121.	148.	142.	144.	121.	138.	141.	117.	112.	100.	105.	1491.
PREC DEF	103.	121.	148.	140.	144.	49.	119.	128.	84.	112.	100.	105.	1343.
MAI	.00	.00	.00	.01	.00	.59	.14	.09	.28	.00	.00	.00	.10

CULIACAN YRS 15 ALT 53 METERS LAT 24 28 LON 107 24

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	SUM OR AV.
MEAN TEMP	19.2	20.4	21.3	23.6	26.0	28.7	28.6	28.0	27.9	26.8	23.0	19.6	24.4
MEAN RS	360.	440.	500.	540.	550.	550.	540.	500.	490.	450.	400.	330.	471.
PRECIP	11.	11.	4.	1.	2.	31.	149.	171.	119.	41.	10.	54.	603.
PREC DEP	0.	0.	0.	0.	0.	12.	94.	110.	73.	19.	0.	28.	422.
POT ET	95.	109.	140.	156.	173.	179.	181.	165.	156.	144.	113.	88.	1700.
PREC DEF	95.	109.	140.	156.	173.	167.	86.	55.	83.	125.	113.	61.	1277.
MAI	.00	.00	.00	.00	.00	.07	.52	.66	.47	.13	.00	.31	.25

CHAMPOTON YRS 15 ALT 2 METERS LAT 19 21 LON 90 43

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	SUM OR AV.
MEAN TEMP	23.1	24.0	26.4	28.0	29.1	28.5	27.7	27.8	27.6	26.6	24.4	23.8	26.4
MEAN RS	340.	440.	480.	480.	480.	490.	450.	490.	400.	350.	390.	340.	427.
PRECIP	45.	25.	14.	21.	72.	127.	217.	193.	192.	191.	34.	53.	1172.
PREC DEP	22.	7.	0.	5.	40.	79.	142.	125.	124.	116.	13.	27.	935.
POT ET	100.	119.	153.	153.	163.	158.	148.	161.	127.	112.	114.	102.	1610.
PREC DEF	78.	112.	153.	149.	122.	80.	6.	36.	2.	-5.	101.	75.	675.
MAI	.22	.06	.00	.03	.25	.50	.96	.78	.98	1.04	.12	.26	.59

CHARCAS YRS 15 ALT 2020 METERS LAT 23 7 LON 101 7

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	SUM OR AV.
MEAN TEMP	11.6	13.5	15.1	17.7	19.6	19.6	19.5	19.0	18.4	16.8	13.8	12.8	16.5
MEAN RS	350.	450.	500.	550.	530.	560.	570.	510.	460.	400.	360.	350.	466.
PRECIP	12.	11.	11.	6.	39.	64.	60.	38.	72.	40.	23.	11.	387.
PREC DEP	0.	0.	0.	0.	17.	35.	32.	17.	40.	18.	6.	0.	228.
POT ET	73.	90.	117.	135.	142.	145.	152.	134.	115.	99.	78.	76.	1357.
PREC DEF	73.	90.	117.	135.	125.	110.	120.	117.	75.	81.	72.	76.	1129.
MAI	.00	.00	.00	.00	.12	.24	.21	.13	.35	.18	.08	.00	.17

CHIAUTLA YRS 15 ALT 910 METERS LAT 15 27 LON 98 36

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	SUM OR AV.
MEAN TEMP	20.2	22.2	24.6	25.8	26.7	25.6	24.7	24.4	24.3	23.2	21.7	20.6	23.7
MEAN RS	350.	460.	520.	500.	510.	450.	500.	500.	450.	450.	420.	400.	459.
PRECIP	2.	3.	10.	2.	71.	152.	150.	199.	188.	65.	4.	1.	847.
PREC DEP	0.	0.	0.	0.	40.	97.	95.	129.	122.	36.	0.	0.	642.
POT ET	95.	119.	158.	152.	163.	136.	153.	152.	132.	132.	115.	110.	1618.
PREC DEF	95.	119.	158.	152.	124.	40.	58.	23.	10.	97.	115.	110.	976.
MAI	.00	.00	.00	.00	.24	.71	.62	.85	.93	.27	.00	.00	.40

CHICONTEPEC YRS 15 ALT 595 METERS LAT 20 59 LON 98 10

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	SUM OR AV.
MEAN TEMP	15.1	17.9	19.8	23.1	25.1	25.5	24.3	24.9	24.1	23.1	19.2	16.1	21.5
MEAN RS	350.	440.	470.	510.	500.	480.	440.	470.	450.	390.	360.	340.	433.
PRECIP	66.	70.	77.	48.	145.	291.	246.	178.	360.	212.	104.	67.	1865.
PREC DEP	36.	39.	44.	23.	92.	194.	162.	115.	242.	138.	63.	37.	1558.
POT ET	82.	101.	126.	145.	154.	145.	133.	144.	131.	114.	92.	82.	1451.
PREC DEF	46.	62.	82.	121.	63.	-49.	-29.	30.	-111.	-24.	29.	46.	-107.
MAI	.44	.38	.35	.16	.59	1.34	1.22	.80	1.85	1.21	.68	.45	1.07

TABLE 3 CLIMATE AND MOISTURE AVAILABILITY INDICES FOR MEXICO

CHIHUAHUA YRS 15 ALT 1422 METERS LAT 28 38 LON 106 4

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	SUM OR AV.
MEAN TEMP	9.6	11.8	14.9	19.7	23.1	26.7	25.1	24.2	22.7	18.2	13.3	9.2	18.1
MEAN RS	340.	460.	520.	610.	620.	630.	620.	580.	560.	450.	380.	330.	508.
PRECIP	4.	5.	9.	8.	10.	24.	80.	96.	94.	37.	8.	21.	395.
PREC DEP	0.	0.	0.	0.	0.	7.	46.	57.	56.	16.	0.	5.	235.
POT ET	66.	87.	121.	154.	182.	195.	191.	175.	156.	116.	81.	63.	1589.
PREC DEF	66.	87.	121.	154.	182.	188.	146.	118.	99.	100.	81.	58.	1353.
MAI	.00	.00	.00	.00	.00	.04	.24	.32	.36	.13	.00	.08	.15

CHOIX YRS 15 ALT 310 METERS LAT 26 43 LON 105 16

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	SUM OR AV.
MEAN TEMP	17.7	19.1	21.0	24.1	27.6	31.2	29.8	28.5	28.2	26.3	22.1	18.1	24.5
MEAN RS	360.	460.	520.	540.	560.	610.	560.	550.	530.	440.	390.	350.	499.
PRECIP	22.	24.	9.	6.	4.	45.	205.	192.	129.	47.	[illegible]	71.	765.
PREC DEP	5.	7.	0.	0.	0.	21.	134.	117.	80.	23.	5.	39.	569.
POT ET	91.	110.	145.	157.	183.	209.	192.	184.	170.	140.	108.	90.	1780.
PREC DEF	86.	103.	145.	157.	183.	188.	59.	67.	90.	117.	103.	50.	1211.
MAI	.06	.06	.00	.00	.00	.10	.70	.64	.47	.17	.05	.44	.32

DOLORES HIDALGO YRS 15 ALT 1895 METERS LAT 21 9 LON 100 56

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	SUM OR AV.
MEAN TEMP	13.6	15.5	17.7	19.9	21.4	20.9	20.6	20.5	20.0	18.1	15.9	14.3	18.2
MEAN RS	370.	470.	520.	520.	510.	490.	450.	490.	450.	390.	370.	360.	449.
PRECIP	11.	6.	9.	7.	30.	92.	129.	94.	129.	35.	10.	14.	555.
PREC DEP	0.	0.	0.	0.	11.	47.	80.	56.	81.	14.	0.	0.	380.
POT ET	83.	101.	132.	136.	143.	131.	124.	134.	118.	100.	86.	92.	1370.
PREC DEF	83.	101.	132.	136.	132.	84.	44.	79.	37.	86.	86.	82.	990.
MAI	.00	.00	.00	.00	.08	.36	.65	.41	.69	.14	.00	.00	.28

DURANGO YRS 15 ALT 1897 METERS LAT 24 1 LON 104 40

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	SUM OR AV.
MEAN TEMP	11.6	13.1	15.6	18.4	20.8	22.2	20.2	20.1	19.3	17.7	14.4	12.1	17.1
MEAN RS	350.	460.	520.	540.	540.	560.	500.	500.	470.	410.	400.	350.	467.
PRECIP	13.	9.	1.	3.	13.	61.	125.	91.	101.	31.	14.	19.	483.
PREC DEP	0.	0.	0.	0.	0.	33.	78.	53.	61.	12.	0.	3.	315.
POT ET	73.	91.	124.	135.	149.	156.	136.	136.	121.	104.	89.	74.	1388.
PREC DEF	73.	91.	124.	135.	149.	123.	58.	82.	60.	92.	89.	71.	1073.
MAI	.00	.00	.00	.00	.00	.21	.57	.39	.50	.11	.00	.04	.23

EJUTLA YRS 15 ALT 1439 METERS LAT 16 33 LON 96 43

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	SUM OR AV.
MEAN TEMP	18.7	21.3	22.9	23.6	24.0	22.9	22.1	22.9	22.4	21.0	19.5	19.3	21.7
MEAN RS	350.	460.	510.	460.	500.	390.	470.	420.	420.	400.	400.	360.	428.
PRECIP	0.	0.	1.	9.	88.	146.	81.	76.	152.	48.	2.	0.	602.
PREC DEP	0.	0.	0.	0.	51.	92.	47.	44.	96.	23.	0.	0.	422.
POT ET	91.	116.	149.	132.	150.	110.	135.	123.	117.	111.	103.	95.	1434.
PREC DEF	91.	116.	149.	132.	99.	18.	89.	79.	21.	88.	103.	95.	1012.
MAI	.00	.00	.00	.00	.34	.83	.34	.35	.82	.21	.00	.00	.29

ENRAMADAS LAS YRS 15 ALT 222 METERS LAT 25 29 LON 99 31

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	SUM OR AV.
MEAN TEMP	15.7	17.4	20.5	24.7	28.0	28.5	29.7	30.0	27.8	24.8	19.0	15.0	23.4
MEAN RS	300.	400.	450.	500.	550.	600.	610.	540.	470.	420.	310.	290.	453.
PRECIP	33.	16.	14.	36.	160.	82.	85.	80.	166.	45.	23.	18.	697.
PREC DEP	13.	1.	0.	15.	60.	47.	49.	46.	106.	21.	6.	3.	507.
POT ET	72.	91.	123.	148.	182.	194.	209.	186.	150.	129.	79.	68.	1630.
PREC DEF	59.	90.	123.	132.	121.	146.	160.	141.	43.	107.	73.	65.	1123.
MAI	.18	.01	.00	.10	.33	.24	.23	.24	.71	.17	.09	.04	.31

TABLE 3 CLIMATE AND MOISTURE AVAILABILITY INDICES FOR MEXICO

ENSENADA YRS 15 ALT 13 METERS LAT 31 52 LON 116 38

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	SUM OR AV.
MEAN TEMP	12.7	13.4	14.3	15.3	17.1	18.2	20.2	21.0	19.3	17.8	16.1	13.9	16.6
MEAN RS	290.	370.	500.	510.	620.	700.	650.	610.	550.	410.	350.	300.	488.
PRECIP	78.	67.	32.	31.	11.	5.	2.	0.	3.	17.	20.	65.	331.
PREC DEP	45.	37.	13.	12.	0.	0.	0.	0.	0.	2.	4.	35.	176.
POT ET	63.	74.	114.	116.	154.	174.	177.	170.	141.	104.	82.	68.	1430.
PREC DEF	18.	37.	101.	104.	154.	174.	177.	170.	141.	102.	78.	32.	1259.
MAT	.71	.50	.11	.10	.00	.00	.00	.00	.00	.02	.05	.52	.12

ESPERANZA LA YRS 15 ALT 1000 METERS LAT 19 23 LON 103 30

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	SUM OR AV.
MEAN TEMP	21.1	21.9	22.7	24.2	25.4	24.7	23.9	23.3	23.2	23.0	22.2	21.5	23.1
MEAN RS	400.	460.	500.	510.	510.	470.	500.	530.	460.	420.	410.	380.	462.
PRECIP	13.	9.	0.	1.	8.	107.	139.	171.	150.	62.	17.	13.	690.
PREC DEP	0.	0.	0.	0.	0.	65.	87.	109.	95.	33.	2.	0.	501.
POT ET	111.	118.	145.	149.	159.	139.	149.	156.	131.	123.	114.	107.	1602.
PREC DEF	111.	118.	145.	149.	159.	74.	62.	47.	36.	90.	112.	107.	1101.
MAT	.00	.00	.00	.00	.00	.47	.58	.70	.73	.27	.02	.00	.31

ETLA YRS 15 ALT 0 METERS LAT 17 13 LON 96 47

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	SUM OR AV.
MEAN TEMP	16.0	17.7	19.3	21.4	21.7	21.2	20.1	20.2	20.0	19.0	17.3	16.6	19.3
MEAN RS	340.	460.	510.	460.	500.	410.	450.	440.	400.	370.	350.	350.	420.
PRECIP	1.	3.	3.	23.	73.	121.	112.	93.	83.	51.	12.	12.	586.
PREC DEP	0.	0.	0.	6.	41.	75.	68.	55.	49.	26.	0.	0.	407.
POT ET	82.	105.	138.	125.	147.	111.	127.	120.	105.	97.	85.	96.	1317.
PREC DEF	82.	105.	139.	119.	101.	36.	54.	65.	56.	72.	85.	96.	910.
MAT	.00	.00	.00	.05	.29	.67	.56	.46	.46	.26	.00	.00	.31

FLOR DE JIMULCO YRS 15 ALT 1920 METERS LAT 25 7 LON 103 18

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	SUM OR AV.
MEAN TEMP	14.2	16.8	18.3	22.6	25.4	27.2	26.3	26.0	24.8	22.5	17.9	13.9	21.3
MEAN RS	350.	460.	520.	550.	550.	610.	590.	540.	490.	420.	360.	340.	478.
PRECIP	8.	8.	2.	3.	10.	24.	52.	42.	42.	17.	16.	11.	236.
PREC DEP	0.	0.	0.	0.	0.	7.	26.	20.	20.	2.	1.	0.	92.
POT ET	80.	103.	134.	154.	171.	192.	175.	170.	145.	121.	89.	77.	1610.
PREC DEF	80.	103.	134.	154.	171.	185.	149.	151.	126.	120.	88.	77.	1518.
MAT	.00	.00	.00	.00	.00	.04	.15	.12	.13	.01	.01	.00	.06

FRESNILLO YRS 15 ALT 2250 METERS LAT 23 10 LON 102 53

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	SUM OR AV.
MEAN TEMP	11.4	13.4	15.9	19.0	21.5	21.7	19.8	20.0	19.7	18.0	14.5	12.8	17.3
MEAN RS	360.	460.	520.	550.	540.	530.	520.	500.	460.	400.	360.	350.	462.
PRECIP	10.	1.	0.	5.	16.	57.	104.	69.	80.	30.	15.	19.	406.
PREC DEP	0.	0.	0.	0.	1.	30.	63.	38.	46.	11.	0.	4.	245.
POT ET	75.	92.	125.	140.	152.	145.	140.	135.	119.	102.	80.	76.	1382.
PREC DEF	75.	92.	125.	140.	151.	116.	77.	97.	73.	91.	80.	73.	1137.
MAT	.00	.00	.00	.00	.01	.21	[illegible]	.28	.39	.11	.00	.05	.18

FUERTE EL YRS 15 ALT 114 METERS LAT 26 25 LON 108 30

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	SUM OR AV.
MEAN TEMP	18.0	19.5	21.5	24.4	27.4	31.8	31.8	30.7	30.4	28.3	23.0	18.7	25.5
MEAN RS	360.	400.	500.	550.	570.	610.	590.	540.	550.	460.	400.	340.	488.
PRECIP	21.	19.	4.	1.	2.	22.	165.	134.	93.	42.	13.	54.	568.
PREC DEP	5.	3.	0.	0.	0.	5.	105.	84.	55.	19.	0.	28.	391.
POT ET	92.	96.	141.	161.	186.	212.	212.	189.	185.	153.	113.	89.	1829.
PREC DEF	87.	93.	141.	161.	186.	207.	106.	106.	130.	134.	113.	61.	1438.
MAT	.05	.03	.00	.00	.00	.02	.50	.44	.30	.13	.00	.31	.21

TABLE 3 CLIMATE AND MOISTURE AVAILABILITY INDICES FOR MEXICO

GALEANA YRS 15 ALT 1653 METERS LAT 24 50 LON 100 4

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	SUM OR AV.
MEAN TEMP	13.4	15.3	16.1	19.0	20.5	21.2	21.0	20.8	20.3	18.8	15.5	13.8	18.0
MEAN RS	330.	420.	470.	550.	550.	600.	580.	540.	470.	410.	340.	300.	463.
PRECIP	23.	20.	9.	11.	58.	73.	53.	38.	101.	44.	26.	16.	473.
PREC DEP	6.	4.	0.	0.	31.	41.	27.	17.	61.	21.	8.	1.	306.
POT ET	73.	99.	114.	140.	151.	162.	161.	149.	124.	107.	78.	67.	1416.
PREC DEF	67.	86.	114.	140.	120.	121.	134.	133.	63.	86.	70.	66.	1111.
MAI	.08	.04	.00	.00	.20	.26	.17	.11	.49	.19	.11	.02	.22

GOGORRON YRS 15 ALT 0 METERS LAT 21 50 LON 100 51

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	SUM OR AV.
MEAN TEMP	13.9	15.8	18.0	20.0	20.7	20.5	20.0	20.2	19.4	17.9	16.5	15.2	18.2
MEAN RS	360.	450.	520.	540.	510.	470.	450.	480.	450.	390.	380.	360.	447.
PRECIP	4.	3.	15.	8.	27.	75.	54.	42.	53.	26.	23.	15.	343.
PREC DEP	0.	0.	1.	0.	9.	42.	28.	19.	27.	8.	6.	0.	189.
POT ET	81.	97.	133.	141.	141.	125.	122.	131.	116.	99.	90.	85.	1361.
PREC DEF	81.	97.	132.	141.	132.	82.	94.	111.	88.	91.	84.	84.	1171.
MAI	.00	.00	.01	.00	.06	.34	.23	.15	.24	.08	.06	.01	.14

GONZALEZ YRS 15 ALT 2139 METERS LAT 21 29 LON 101 13

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	SUM OR AV.
MEAN TEMP	12.5	14.5	16.7	18.7	20.3	19.8	18.7	18.8	19.4	16.6	14.6	13.5	16.9
MEAN RS	390.	460.	520.	530.	500.	470.	450.	460.	450.	390.	390.	360.	447.
PRECIP	12.	7.	10.	6.	31.	94.	99.	73.	98.	33.	24.	18.	503.
PREC DEP	0.	0.	0.	0.	12.	56.	59.	41.	59.	13.	7.	2.	333.
POT ET	84.	96.	129.	134.	136.	122.	119.	120.	113.	96.	87.	80.	1314.
PREC DEF	84.	96.	129.	134.	125.	66.	58.	79.	54.	83.	81.	78.	981.
MAI	.00	.00	.00	.00	.08	.46	.50	.34	.52	.13	.07	.03	.25

GONZALEZ VILLA YRS 15 ALT 1204 METERS LAT 30 38 LON 106 31

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	SUM OR AV.
MEAN TEMP	4.9	7.4	11.5	16.6	22.3	25.6	25.5	24.4	22.5	17.4	9.4	4.0	16.0
MEAN RS	320.	430.	500.	650.	650.	640.	660.	600.	560.	460.	360.	300.	511.
PRECIP	3.	7.	6.	9.	10.	8.	42.	43.	28.	20.	8.	9.	191.
PREC DEP	0.	0.	0.	0.	0.	0.	20.	20.	10.	4.	0.	0.	52.
POT ET	51.	69.	104.	154.	187.	194.	206.	182.	157.	116.	67.	46.	1537.
PREC DEF	51.	69.	104.	154.	187.	194.	186.	162.	147.	112.	67.	46.	1490.
MAI	.00	.00	.00	.00	.00	.00	.09	.11	.06	.03	.00	.00	.03

GUADALAJARA YRS 15 ALT 1589 METERS LAT 20 41 LON 103 20

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	SUM OR AV.
MEAN TEMP	14.6	16.0	18.4	21.2	22.8	22.2	20.3	20.7	19.9	18.9	16.8	15.2	18.9
MEAN RS	410.	460.	510.	520.	520.	480.	470.	470.	450.	410.	400.	370.	456.
PRECIP	17.	5.	3.	2.	19.	191.	250.	198.	177.	52.	20.	19.	953.
PREC DEP	2.	0.	0.	0.	3.	124.	165.	129.	114.	27.	4.	3.	730.
POT ET	95.	100.	132.	141.	151.	133.	128.	128.	118.	108.	96.	87.	1416.
PREC DEF	93.	100.	132.	141.	148.	10.	-37.	-1.	4.	81.	92.	84.	678.
MAI	.02	.00	.00	.00	.02	.93	1.29	1.01	.97	.25	.04	.04	.57

GUADALUPE DE CAL YRS 15 ALT 1113 METERS LAT 26 6 LON 107 6

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	SUM OR AV.
MEAN TEMP	6.0	6.9	8.0	11.3	14.4	17.6	17.1	16.5	16.7	14.1	8.9	7.2	12.1
MEAN RS	360.	450.	500.	600.	570.	620.	500.	530.	550.	460.	400.	340.	497.
PRECIP	60.	56.	35.	6.	24.	84.	257.	221.	156.	64.	29.	84.	1076.
PREC DEP	32.	29.	14.	0.	7.	48.	170.	145.	100.	35.	11.	48.	849.
POT ET	61.	71.	91.	120.	131.	152.	145.	130.	131.	104.	73.	60.	1268.
PREC DEF	28.	41.	77.	120.	124.	103.	-25.	-15.	31.	69.	62.	12.	419.
MAI	.53	.42	.16	.00	.05	.32	1.17	1.12	.76	.34	.15	.81	.67

TABLE 3 CLIMATE AND MOISTURE AVAILABILITY INDICES FOR MEXICO

GUADALUPE VICTORIA YRS 15 ALT 1982 METERS LAT 24 25 LON 104 8

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	SUM OR AV.
MEAN TEMP	14.2	13.8	15.2	17.0	18.5	19.3	19.4	18.0	17.4	16.5	15.4	14.3	16.6
MEAN RS	370.	410.	490.	550.	540.	590.	540.	500.	490.	410.	400.	350.	470.
PRECIP	8.	5.	3.	2.	5.	47.	101.	97.	86.	27.	8.	14.	401.
PREC DEP	0.	0.	0.	0.	0.	23.	60.	58.	50.	9.	0.	0.	241.
POT ET	84.	93.	115.	132.	140.	151.	144.	128.	119.	100.	92.	80.	1369.
PREC DEF	84.	83.	115.	132.	140.	128.	83.	70.	69.	92.	92.	80.	1128.
MAI	.00	.00	.00	.00	.00	.15	.42	.45	.42	.09	.00	.00	.18

GUANACEVI YRS 15 ALT 0 METERS LAT 25 55 LON 105 57

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	SUM OR AV.
MEAN TEMP	8.9	10.4	12.9	15.5	18.2	21.7	19.1	18.6	18.0	15.7	12.2	9.3	15.0
MEAN RS	360.	440.	530.	550.	550.	600.	550.	520.	500.	440.	400.	350.	482.
PRECIP	17.	13.	13.	8.	14.	65.	145.	155.	117.	38.	13.	50.	646.
PREC DEP	2.	0.	0.	0.	0.	35.	92.	99.	72.	17.	0.	25.	463.
POT ET	68.	79.	114.	126.	142.	165.	145.	135.	124.	105.	83.	67.	1352.
PREC DEF	66.	79.	114.	126.	142.	129.	53.	37.	52.	88.	83.	42.	890.
MAI	.03	.00	.00	.00	.00	.21	.63	.73	.58	.16	.00	.37	.34

GUANAJUATO YRS 15 ALT 2036 METERS LAT 21 1 LON 101 15

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	SUM OR AV.
MEAN TEMP	13.9	15.4	17.9	20.1	21.4	20.1	18.8	18.8	18.4	17.5	15.8	14.8	17.7
MEAN RS	390.	460.	520.	530.	500.	470.	450.	460.	450.	390.	370.	360.	446.
PRECIP	12.	8.	6.	6.	27.	136.	166.	140.	153.	51.	19.	14.	740.
PREC DEP	0.	0.	0.	0.	9.	85.	106.	88.	97.	26.	3.	0.	546.
POT ET	88.	98.	132.	139.	140.	123.	118.	120.	113.	98.	86.	84.	1340.
PREC DEF	88.	98.	132.	139.	131.	38.	11.	32.	15.	72.	83.	84.	793.
MAI	.00	.00	.00	.00	.07	.69	.90	.73	.86	.26	.03	.00	.41

GUAYAMAS YRS 15 ALT 3 METERS LAT 27 55 LON 110 53

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	SUM OR AV.
MEAN TEMP	17.7	18.9	20.7	22.8	25.5	28.8	30.7	30.5	30.2	27.3	22.6	18.6	24.5
MEAN RS	360.	410.	530.	600.	650.	660.	620.	570.	560.	530.	390.	320.	518.
PRECIP	8.	6.	5.	3.	3.	1.	47.	75.	55.	9.	11.	29.	251.
PREC DEP	0.	0.	0.	0.	0.	0.	23.	43.	28.	0.	0.	10.	106.
POT ET	91.	97.	146.	169.	203.	215.	217.	206.	188.	172.	109.	83.	1897.
PREC DEF	91.	97.	146.	169.	203.	215.	[illegible]	163.	160.	172.	109.	73.	1791.
MAI	.00	.00	.00	.00	.00	.00	[illegible]	.21	.15	.00	.00	.12	.06

GUERRERO YRS 15 ALT 2010 METERS LAT 28 33 LON 107 30

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	SUM OR AV.
MEAN TEMP	4.1	6.0	8.7	11.7	14.9	18.5	19.3	18.2	16.8	8.3	8.4	4.8	11.6
MEAN RS	350.	440.	530.	600.	[illegible]	640.	630.	570.	560.	470.	390.	330.	511.
PRECIP	10.	11.	5.	6.	23.	33.	118.	119.	81.	24.	10.	29.	458.
PREC DEP	0.	0.	0.	0.	0.	13.	72.	73.	47.	7.	0.	11.	292.
POT ET	54.	67.	98.	122.	144.	161.	167.	147.	134.	87.	70.	53.	1302.
PREC DEF	54.	67.	98.	122.	144.	148.	95.	73.	87.	80.	70.	42.	1010.
MAI	.00	.00	.00	.00	.00	.08	.43	.50	.35	.08	.00	.20	.22

GUERRERO VILLA YRS 15 ALT 67 METERS LAT 22 0 LON 98 46

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	SUM OR AV.
MEAN TEMP	19.8	20.9	23.8	27.3	28.8	28.4	28.3	28.3	27.8	26.3	22.6	20.0	25.2
MEAN RS	340.	440.	470.	550.	530.	500.	460.	500.	460.	400.	350.	340.	445.
PRECIP	35.	32.	9.	22.	70.	168.	222.	177.	232.	94.	32.	22.	1115.
PREC DEP	15.	12.	0.	5.	39.	108.	146.	114.	153.	56.	12.	5.	884.
POT ET	91.	110.	140.	175.	178.	161.	153.	166.	146.	127.	98.	92.	1638.
PREC DEF	77.	98.	140.	169.	139.	53.	7.	52.	-6.	71.	86.	87.	755.
MAI	.16	.11	.00	.03	.22	.67	.95	.69	1.04	.44	.13	.06	.54

TABLE 3 CLIMATE AND MOISTURE AVAILABILITY INDICES FOR MEXICO

HERMOSILLO YRS 15 ALT 210 METERS LAT 29 5 LON 110 58

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	SUM OR AV.
MEAN TEMP	15.7	17.3	20.7	22.9	26.4	31.0	32.0	31.4	30.3	26.0	21.1	15.6	24.2
MEAN RS	340.	410.	520.	630.	660.	690.	650.	600.	570.	470.	400.	320.	522.
PRECIP	2.	15.	5.	2.	2.	4.	71.	84.	63.	41.	6.	26.	320.
PREC DEP	0.	1.	0.	0.	0.	0.	40.	49.	34.	19.	0.	8.	168.
POT ET	81.	93.	142.	178.	210.	236.	234.	214.	192.	148.	108.	76.	1911.
PREC DEF	81.	92.	142.	178.	210.	236.	195.	165.	158.	130.	108.	68.	1743.
MAI	.00	.01	.00	.00	.00	.00	.17	.23	.18	[illegible]	.00	.11	.09

HIDALGO YRS 15 ALT 2000 METERS LAT 19 40 LON 100 32

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	SUM OR AV.
MEAN TEMP	13.6	14.6	16.0	17.7	19.4	19.6	18.8	18.6	18.4	17.5	15.7	14.3	17.0
MEAN RS	400.	460.	520.	510.	500.	460.	440.	530.	440.	390.	400.	370.	452.
PRECIP	20.	15.	8.	13.	48.	146.	171.	179.	166.	63.	41.	21.	891.
PREC DEP	4.	0.	0.	0.	24.	92.	110.	115.	106.	34.	18.	4.	681.
POT ET	89.	96.	125.	125.	133.	119.	115.	138.	110.	98.	92.	84.	1320.
PREC DEF	85.	96.	125.	125.	109.	27.	5.	23.	4.	64.	74.	80.	645.
MAI	.05	.00	.00	.00	.18	.77	.95	.84	.96	.35	.20	.05	.51

HIDALGO DEL PARRAL YRS 15 ALT 1652 METERS LAT 26 56 LON 105 39

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	SUM OR AV.
MEAN TEMP	10.7	11.9	13.4	17.3	20.5	23.8	22.9	22.1	20.6	19.3	14.2	10.6	17.2
MEAN RS	350.	450.	520.	550.	570.	610.	570.	550.	520.	440.	400.	350.	490.
PRECIP	5.	4.	5.	2.	8.	44.	124.	117.	117.	46.	19.	19.	509.
PREC DEP	0.	0.	0.	0.	0.	21.	77.	72.	72.	21.	4.	3.	338.
POT ET	71.	86.	115.	133.	156.	176.	166.	157.	138.	113.	88.	70.	1472.
PREC DEF	71.	86.	115.	133.	156.	155.	89.	86.	67.	93.	95.	67.	1135.
MAI	.00	.00	.00	.00	.00	.12	.46	.45	.52	.19	.04	.04	.23

HORMIGUERO EL YRS 15 ALT 1753 METERS LAT 27 2 LON 105 42

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	SUM OR AV.
MEAN TEMP	10.4	12.3	13.9	19.6	22.0	23.9	22.3	21.1	20.7	18.4	13.9	11.2	17.4
MEAN RS	350.	450.	520.	550.	590.	620.	600.	560.	550.	450.	370.	340.	496.
PRECIP	15.	10.	4.	2.	11.	57.	139.	133.	126.	41.	17.	21.	576.
PREC DEP	0.	0.	0.	0.	0.	30.	88.	83.	78.	19.	2.	5.	398.
POT ET	70.	87.	117.	139.	168.	190.	173.	156.	147.	110.	81.	70.	1503.
PREC DEF	69.	87.	117.	139.	168.	150.	85.	73.	69.	97.	79.	65.	1105.
MAI	.01	.00	.00	.00	.00	.17	.51	.53	.53	.16	.02	.07	.26

HUAJUAPAN YRS 15 ALT 1596 METERS LAT 17 48 LON 97 47

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	SUM OR AV.
MEAN TEMP	17.2	18.9	21.2	22.9	24.0	23.0	22.1	21.9	21.3	20.0	18.0	17.6	20.7
MEAN RS	350.	470.	510.	500.	480.	400.	450.	450.	420.	370.	370.	350.	427.
PRECIP	1.	3.	10.	17.	95.	140.	120.	117.	159.	57.	9.	12.	740.
PREC DEP	0.	0.	0.	2.	56.	98.	74.	72.	101.	30.	0.	0.	546.
POT ET	87.	111.	143.	141.	144.	113.	129.	128.	114.	100.	91.	88.	1391.
PREC DEF	87.	111.	143.	139.	88.	25.	55.	56.	13.	70.	91.	88.	845.
MAI	.00	.00	.00	.01	.39	.78	.57	.56	.89	.30	.00	.00	.39

HUATUSCO YRS 15 ALT 1343 METERS LAT 19 9 LON 96 57

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	SUM OR AV.
MEAN TEMP	15.5	17.2	17.2	20.0	20.9	19.8	19.6	19.6	19.7	19.1	17.1	15.8	18.5
MEAN RS	340.	430.	480.	490.	500.	450.	450.	450.	430.	400.	350.	340.	427.
PRECIP	47.	46.	41.	83.	169.	300.	387.	306.	430.	152.	61.	56.	2078.
PREC DEP	23.	23.	19.	48.	109.	200.	261.	204.	291.	97.	33.	29.	1750.
POT ET	81.	97.	120.	128.	139.	117.	120.	123.	112.	106.	84.	81.	1308.
PREC DEF	58.	75.	102.	80.	30.	-83.	-140.	-81.	-179.	9.	51.	52.	-442.
MAI	.28	.23	.16	.38	.78	1.71	2.17	1.66	2.61	.92	.39	.36	1.34

TABLE 3 CLIMATE AND MOISTURE AVAILABILITY INDICES FOR MEXICO

HUAUCHINANGO YRS 15 ALT 1600 METERS LAT 20 10 LON 98 3

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	SUM OR AV.
MEAN TEMP	11.2	12.9	14.5	17.7	19.1	18.6	17.8	17.7	17.2	15.9	12.9	11.8	15.6
MEAN RS	370.	450.	490.	510.	500.	470.	450.	470.	450.	390.	360.	350.	438.
PRECIP	59.	49.	50.	56.	91.	366.	399.	355.	407.	257.	103.	53.	2239.
PREC DEP	31.	24.	25.	29.	54.	246.	269.	238.	271.	170.	62.	27.	1895.
POT ET	76.	89.	113.	125.	133.	118.	114.	119.	109.	92.	76.	73.	1237.
PREC DEF	45.	64.	88.	96.	79.	-128.	-155.	-119.	-162.	-78.	14.	46.	-658.
MAI	.41	.27	.22	.23	.40	2.08	2.35	2.00	2.49	1.85	.82	.37	1.53

HUEJOTZINGO YRS 15 ALT 2200 METERS LAT 19 9 LON 98 24

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	SUM OR AV.
MEAN TEMP	13.2	15.2	17.6	17.9	19.4	18.9	18.4	17.0	16.8	16.9	14.6	13.3	16.6
MEAN RS	400.	450.	500.	510.	490.	460.	440.	450.	440.	380.	380.	350.	438.
PRECIP	3.	5.	4.	18.	72.	160.	197.	143.	152.	67.	15.	3.	838.
PREC DEP	0.	0.	0.	3.	40.	102.	128.	90.	96.	37.	0.	0.	634.
POT ET	88.	96.	126.	126.	130.	117.	114.	112.	105.	94.	85.	77.	1270.
PREC DEF	88.	96.	126.	123.	90.	15.	-14.	22.	9.	57.	85.	77.	636.
MAI	.00	.00	.00	.02	.31	.87	1.12	.81	.92	.39	.01	.00	.50

HUETAMO YRS 15 ALT 356 METERS LAT 18 40 LON 100 54

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	SUM OR AV.
MEAN TEMP	24.1	25.8	28.4	31.2	33.2	31.7	29.6	28.6	28.3	28.0	26.7	25.7	28.4
MEAN RS	400.	470.	520.	520.	500.	450.	450.	460.	450.	400.	400.	390.	450.
PRECIP	2.	3.	1.	2.	21.	162.	204.	204.	199.	51.	14.	10.	874.
PREC DEP	0.	0.	0.	0.	5.	103.	133.	133.	130.	25.	0.	0.	666.
POT ET	120.	133.	173.	179.	185.	155.	154.	154.	145.	132.	124.	119.	1773.
PREC DEF	120.	133.	173.	179.	180.	51.	21.	21.	15.	107.	124.	119.	1107.
MAI	.00	.00	.00	.00	.03	.67	.86	.86	.90	.19	.00	.00	.38

HUICHAPAN YRS 15 ALT 2102 METERS LAT 20 23 LON 99 39

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	SUM OR AV.
MEAN TEMP	12.4	13.9	16.2	18.2	19.2	18.1	17.1	17.0	16.8	15.7	14.0	13.2	15.9
MEAN RS	360.	460.	510.	510.	500.	470.	440.	460.	450.	390.	380.	360.	441.
PRECIP	9.	4.	4.	14.	33.	51.	64.	57.	72.	32.	8.	7.	354.
PREC DEP	0.	0.	0.	0.	13.	26.	35.	30.	40.	13.	0.	0.	199.
POT ET	77.	94.	124.	127.	132.	117.	110.	114.	107.	92.	83.	79.	1257.
PREC DEF	77.	94.	124.	127.	119.	91.	75.	84.	67.	79.	83.	79.	1058.
MAI	.00	.00	.00	.00	.10	.22	.32	.26	.37	.14	.00	.00	.16

HUIXQUILUCAN YRS 15 ALT 2700 METERS LAT 19 22 LON 99 22

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	SUM OR AV.
MEAN TEMP	11.2	12.6	14.9	15.7	16.1	15.2	14.2	14.3	13.1	12.9	11.9	11.8	13.7
MEAN RS	380.	460.	520.	510.	500.	460.	430.	450.	440.	380.	380.	360.	439.
PRECIP	10.	10.	13.	30.	82.	220.	236.	213.	218.	88.	27.	10.	1159.
PREC DEP	0.	0.	0.	11.	47.	144.	155.	139.	143.	52.	9.	0.	923.
POT ET	78.	90.	121.	118.	121.	105.	98.	103.	94.	83.	78.	76.	1163.
PREC DEF	78.	90.	121.	107.	73.	-40.	-57.	-37.	-49.	31.	68.	76.	240.
MAI	.00	.00	.00	.09	.39	1.38	1.59	1.36	1.52	.62	.12	.00	.79

IGUALA YRS 15 ALT 735 METERS LAT 18 22 LON 99 33

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	SUM OR AV.
MEAN TEMP	24.4	26.1	28.3	30.0	30.7	28.7	27.4	27.0	26.7	26.5	25.4	24.4	27.1
MEAN RS	400.	470.	530.	510.	500.	450.	440.	450.	440.	390.	390.	370.	445.
PRECIP	1.	1.	4.	6.	54.	226.	232.	259.	237.	73.	19.	4.	1115.
PREC DEP	0.	0.	0.	0.	28.	148.	152.	171.	156.	41.	4.	0.	883.
POT ET	121.	134.	176.	170.	175.	146.	143.	145.	136.	124.	117.	112.	1702.
PREC DEF	121.	134.	176.	170.	147.	-2.	-9.	-26.	-19.	84.	114.	112.	819.
MAI	.00	.00	.00	.00	.16	1.01	1.06	1.18	1.14	.33	.03	.00	.52

TABLE 3 CLIMATE AND MOISTURE AVAILABILITY INDICES FOR MEXICO

IRAPUATO YRS 15 ALT 1734 METERS LAT 20 40 LON 101 21

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	SUM OR AV.
MEAN TEMP	14.6	16.5	18.9	21.3	23.1	22.6	21.2	21.0	20.5	19.6	16.9	15.3	19.3
MEAN RS	400.	470.	520.	530.	500.	490.	450.	460.	440.	390.	400.	370.	451.
PRECIP	10.	12.	17.	5.	24.	124.	187.	161.	162.	35.	14.	10.	755.
PREC DEP	0.	0.	0.	0.	7.	77.	118.	103.	104.	15.	0.	0.	560.
POT ET	92.	104.	136.	144.	147.	175.	126.	128.	117.	104.	96.	87.	1415.
PREC DEF	92.	104.	136.	144.	140.	98.	8.	25.	13.	90.	96.	87.	856.
MAI	.00	.00	.00	.00	.04	.57	.94	.81	.89	.14	.00	.00	.40

IXMIQUILPAN YRS 15 ALT 1745 METERS LAT 20 29 LON 99 13

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	SUM OR AV.
MEAN TEMP	14.1	15.4	18.7	20.2	22.0	21.6	21.2	20.8	20.4	19.2	16.0	14.6	18.6
MEAN RS	360.	450.	510.	520.	500.	470.	440.	450.	440.	390.	370.	350.	438.
PRECIP	4.	4.	9.	15.	25.	42.	49.	38.	62.	31.	4.	5.	287.
PREC DEP	0.	0.	0.	0.	8.	20.	24.	17.	33.	12.	0.	0.	139.
POT ET	82.	96.	131.	137.	143.	128.	123.	124.	116.	100.	86.	81.	1349.
PREC DEF	82.	96.	131.	137.	135.	109.	99.	108.	83.	89.	86.	81.	1210.
MAI	.00	.00	.00	.00	.05	.15	.20	.13	.29	.12	.00	.00	.10

IXTLAN DE JUAREZ YRS 15 ALT 1700 METERS LAT 17 20 LON 96 30

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	SUM OR AV.
MEAN TEMP	13.4	14.9	16.9	16.9	17.8	16.7	15.9	15.8	15.8	14.9	13.7	14.2	15.5
MEAN RS	400.	470.	480.	450.	460.	400.	430.	440.	400.	370.	350.	350.	417.
PRECIP	9.	9.	6.	15.	93.	163.	168.	119.	211.	154.	50.	17.	1003.
PREC DEP	0.	0.	0.	1.	48.	104.	107.	73.	138.	98.	25.	2.	783.
POT ET	89.	99.	119.	108.	117.	95.	103.	105.	93.	86.	76.	80.	1169.
PREC DEF	89.	99.	119.	107.	69.	-9.	-4.	32.	-45.	-12.	51.	78.	386.
MAI	.00	.00	.00	.01	.41	1.09	1.04	.69	1.49	1.13	.33	.02	.67

JALAPA YRS 15 ALT 1399 METERS LAT 19 32 LON 96 55

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	SUM OR AV.
MEAN TEMP	14.5	15.5	17.0	19.5	20.2	19.4	19.1	19.1	18.8	18.1	15.9	15.2	17.7
MEAN RS	340.	430.	470.	490.	500.	450.	450.	470.	440.	400.	340.	340.	427.
PRECIP	52.	54.	52.	58.	120.	298.	214.	201.	290.	130.	71.	48.	1589.
PREC DEP	27.	28.	26.	31.	74.	199.	140.	131.	193.	91.	40.	23.	1310.
POT ET	78.	92.	117.	126.	136.	116.	119.	124.	111.	103.	79.	80.	1281.
PREC DEF	52.	64.	90.	96.	62.	-83.	-21.	-7.	-82.	22.	39.	57.	-29.
MAI	.34	.30	.23	.24	.54	1.72	1.18	1.05	1.74	.79	.51	.29	1.02

JERECUARO YRS 15 ALT 1786 METERS LAT 20 9 LON 100 25

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	SUM OR AV.
MEAN TEMP	13.5	15.5	17.0	19.3	20.7	20.1	18.5	18.4	18.3	17.2	15.6	14.9	17.4
MEAN RS	370.	460.	520.	520.	500.	470.	440.	460.	440.	390.	380.	360.	442.
PRECIP	11.	12.	10.	13.	41.	119.	195.	153.	139.	54.	18.	18.	785.
PREC DEP	0.	0.	0.	0.	19.	73.	127.	97.	97.	28.	3.	2.	587.
POT ET	82.	99.	129.	133.	138.	123.	114.	119.	110.	97.	88.	94.	1317.
PREC DEF	82.	99.	129.	133.	119.	50.	-13.	22.	22.	70.	85.	92.	730.
MAI	.00	.00	.00	.00	.14	.59	1.11	.82	.80	.29	.03	.03	.45

JONACATEPEC YRS 15 ALT 1300 METERS LAT 18 41 LON 98 48

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	SUM OR AV.
MEAN TEMP	19.3	20.9	22.5	24.2	25.5	24.0	22.8	22.5	22.0	21.4	20.2	19.7	22.1
MEAN RS	370.	470.	510.	500.	490.	440.	440.	450.	430.	380.	360.	360.	433.
PRECIP	4.	4.	5.	7.	52.	147.	174.	195.	204.	53.	7.	3.	854.
PREC DEP	0.	0.	0.	0.	26.	93.	112.	126.	133.	27.	0.	0.	649.
POT ET	98.	118.	147.	146.	153.	128.	129.	130.	119.	107.	95.	97.	1465.
PREC DEF	98.	118.	147.	146.	126.	35.	16.	4.	-14.	79.	95.	97.	817.
MAI	.00	.00	.00	.00	.17	.73	.87	.97	1.12	.25	.00	.00	.44

TABLE 3 CLIMATE AND MOISTURE AVAILABILITY INDICES FOR MEXICO

JUAREZ   YRS 15   ALT 1136 METERS   LAT 31 44   LON 106 29

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	SUM OR AV.
MEAN TEMP	5.4	8.9	12.7	17.8	21.2	25.7	27.0	26.0	22.8	17.2	9.9	6.1	16.7
MEAN RS	320.	380.	540.	650.	690.	670.	660.	610.	570.	460.	370.	300.	518.
PRECIP	6.	10.	8.	8.	15.	12.	29.	33.	24.	24.	9.	9.	187.
PREC DEP	0.	0.	0.	0.	1.	3.	10.	13.	7.	7.	0.	0.	41.
POT ET	52.	65.	115.	160.	193.	203.	213.	192.	161.	115.	70.	51.	1590.
PREC DEF	52.	65.	115.	160.	192.	203.	202.	180.	154.	108.	70.	51.	1549.
MAI	.00	.00	.00	.00	.00	.00	.05	.07	.04	.06	.00	.00	.03

JUNTA LA   YRS 15   ALT 2040 METERS   LAT 28 25   LON 107 20

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	SUM OR AV.
MEAN TEMP	4.7	6.3	10.0	12.5	16.5	19.7	20.0	19.4	18.4	16.0	8.1	6.0	13.1
MEAN RS	330.	440.	540.	600.	620.	640.	610.	560.	560.	470.	380.	330.	507.
PRECIP	3.	2.	2.	1.	9.	58.	129.	120.	38.	35.	4.	16.	419.
PREC DEP	0.	0.	0.	0.	0.	31.	80.	74.	14.	15.	0.	1.	252.
POT ET	52.	68.	106.	125.	152.	166.	165.	149.	140.	113.	67.	55.	1360.
PREC DEF	52.	68.	106.	125.	152.	135.	85.	75.	126.	99.	67.	54.	1107.
MAI	.00	.00	.00	.00	.00	.19	.48	.50	.10	.13	.00	.02	.19

LAGOS   YRS 15   ALT 1979 METERS   LAT 21 22   LON 101 56

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	SUM OR AV.
MEAN TEMP	14.3	16.2	18.[illegible]	21.8	24.4	24.6	23.0	22.9	22.0	20.1	17.3	15.2	20.0
MEAN RS	400.	470.	520.	530.	500.	490.	450.	460.	450.	390.	390.	360.	451.
PRECIP	17.	9.	7.	2.	21.	112.	149.	122.	118.	45.	17.	17.	634.
PREC DEP	2.	0.	0.	0.	5.	68.	94.	75.	72.	22.	2.	2.	453.
POT ET	91.	103.	136.	146.	152.	145.	132.	134.	124.	106.	94.	85.	1448.
PREC DEF	90.	103.	136.	146.	147.	76.	37.	59.	52.	84.	93.	83.	996.
MAI	.02	.00	.00	.00	.03	.47	.72	.56	.58	.21	.02	.02	.31

LAMPAZOS   YRS 15   ALT 339 METERS   LAT 27 2   LON 100 31

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	SUM OR AV.
MEAN TEMP	12.3	15.2	20.2	24.1	26.7	29.2	29.5	29.7	27.0	22.9	17.3	12.1	22.2
MEAN RS	300.	350.	450.	540.	590.	600.	630.	560.	490.	420.	300.	280.	456.
PRECIP	19.	11.	10.	25.	47.	31.	41.	13.	138.	58.	19.	24.	435.
PREC DEP	2.	0.	0.	8.	23.	12.	18.	0.	87.	31.	3.	7.	271.
POT ET	64.	74.	123.	157.	176.	197.	215.	192.	153.	123.	73.	59.	1607.
PREC DEF	62.	74.	123.	150.	154.	186.	197.	192.	66.	92.	70.	53.	1336.
MAI	.04	.00	.00	.05	.13	.06	.09	.00	.57	.25	.04	.11	.17

LEON   YRS 15   ALT 1809 METERS   LAT 21 7   LON 101 41

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	SUM OR AV.
MEAN TEMP	14.4	16.1	18.7	21.2	22.4	22.0	20.1	20.1	19.8	18.7	16.3	15.4	18.8
MEAN RS	400.	470.	520.	530.	500.	490.	450.	460.	450.	390.	390.	360.	451.
PRECIP	12.	6.	4.	2.	23.	108.	165.	138.	133.	38.	18.	13.	660.
PREC DEP	0.	0.	0.	0.	6.	66.	106.	87.	83.	16.	2.	0.	474.
POT ET	92.	103.	136.	143.	146.	135.	122.	125.	117.	102.	92.	85.	1397.
PREC DEF	92.	103.	136.	143.	140.	69.	16.	38.	34.	85.	89.	85.	923.
MAI	.00	.00	.00	.00	.04	.49	.87	.69	.71	.16	.03	.00	.34

LERDO   YRS 15   ALT 1139 METERS   LAV 25 30   LON 103 32

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	SUM OR AV.
MEAN TEMP	13.7	16.3	19.2	23.0	25.9	27.5	26.4	26.4	24.5	21.6	17.3	12.6	21.3
MEAN RS	350.	460.	510.	540.	550.	540.	540.	540.	480.	420.	380.	340.	471.
PRECIP	6.	4.	3.	3.	15.	27.	44.	31.	68.	19.	10.	11.	242.
PREC DEP	0.	0.	0.	0.	1.	9.	21.	12.	34.	3.	0.	0.	98.
POT ET	78.	101.	135.	153.	173.	171.	172.	172.	141.	119.	92.	76.	1583.
PREC DEF	78.	101.	135.	153.	172.	162.	152.	160.	107.	115.	92.	76.	1485.
MAI	.00	.00	.00	.00	.00	.05	.12	.07	.27	.03	.00	.00	.06

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TABLE 3  CLIMATE AND MOISTURE AVAILABILITY INDICES FOR MEXICO
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      LINARES                     YRS 15   ALT  684 METERS    LAT 24 52    LON  99 34

             JAN    FEB    MAR    APR    MAY    JUN    JUL    AUG    SEP    OCT    NOV    DEC  SUM OR AV.

MEAN TEMP   14.8   17.3   19.3   23.1   24.9   26.4   26.8   27.5   25.4   22.7   18.0   14.3      21.7
MEAN RS     330.   430.   440.   500.   550.   570.   580.   540.   470.   410.   330.   290.      453.
PRECIP       30.    15.    20.    52.    92.   100.    99.    61.   188.    81.    31.    31.      801.
PREC DEP     11.     1.     4.    26.    55.    60.    60.    33.   122.    46.    12.    12.      601.
POT ET       77.    97.   117.   142.   169.   175.   186.   176.   141.   119.    82.    66.     1549.
PREC DEF     66.    96.   113.   116.   114.   116.   127.   143.    19.    73.    70.    54.      947.
MAI          .14    .01    .03    .19    .32    .34    .32    .19    .86    .39    .14    .18       .39
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      LOBOS ISLA                  YRS 15   ALT    0 METERS    LAT 21 28    LON  97 13

             JAN    FEB    MAR    APR    MAY    JUN    JUL    AUG    SEP    OCT    NOV    DEC  SUM OR AV.

MEAN TEMP   19.4   20.8   21.7   24.3   26.3   27.3   27.4   27.5   27.7   26.3   23.1   20.1      24.3
MEAN RS     390.   400.   410.   550.   520.   500.   480.   480.   460.   400.   350.   370.      435.
PRECIP       68.    57.    28.    30.    97.   172.   192.   229.   417.   293.   114.    77.     1773.
PREC DEP     38.    30.    10.    11.    58.   110.   124.   150.   282.   195.    69.    44.     1476.
POT ET       90.   100.   116.   161.   165.   157.   156.   157.   145.   127.    99.    90.     1564.
PREC DEF     52.    70.   107.   150.   107.    47.    32.     6.  -137.   -68.    30.    46.       98.
MAI          .42    .30    .08    .07    .35    .70    .80    .96   1.95   1.53    .70    .49       .94
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      LOMAS DEL MIRADOR           YRS 15   ALT    0 METERS    LAT 21 42    LON  99  1

             JAN    FEB    MAR    APR    MAY    JUN    JUL    AUG    SEP    OCT    NOV    DEC  SUM OR AV.

MEAN TEMP   19.1   20.6   22.6   26.4   28.7   28.8   27.7   27.5   26.9   24.9   21.4   19.2      24.5
MEAN RS     350.   450.   500.   550.   510.   490.   450.   490.   460.   390.   360.   350.      445.
PRECIP       37.    32.    20.    44.    89.   176.   251.   205.   406.   188.    47.    20.     1512.
PREC DEP     16.    13.     4.    21.    52.   112.   166.   134.   274.   122.    20.     4.     1241.
POT ET       92.   112.   145.   169.   171.   159.   149.   157.   143.   120.    98.    93.     1607.
PREC DEF     77.    99.   141.   148.   119.    46.   -18.    23.  -131.    -2.    78.    89.      366.
MAI          .17    .11    .03    .12    .30    .71   1.12    .85   1.92   1.02    .20    .04       .77
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      LLANOS VERDE                YRS 15,  ALT    0 METERS    LAT 19 44    LON  98  3

             JAN    FEB    MAR    APR    MAY    JUN    JUL    AUG    SEP    OCT    NOV    DEC  SUM OR AV.

MEAN TEMP   11.4   12.7   14.0   15.3   15.9   15.0   14.7   14.8   13.9   13.7   12.0   12.0      13.6
MEAN RS     370.   440.   490.   510.   500.   450.   440.   450.   440.   390.   360.   350.      432.
PRECIP        8.    19.    14.    27.    49.   134.   127.   108.   139.    85.    33.    11.      756.
PREC DEP      0.     1.     1.     9.    24.    84.    79.    66.    87.    49.    13.     0.      560.
POT ET       77.    85.   111.   116.   120.   107.   100.   104.    96.    86.    74.    74.     1149.
PREC DEF     77.    82.   110.   107.    96.    18.    21.    39.     8.    37.    61.    74.      594.
MAI          .00    .04    .01    .08    .20    .83    .79    .63    .91    .57    .17    .00       .49
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      MACLOVIO HERRERA            YRS 15   ALT  984 METERS    LAT 23  9    LON 105  8

             JAN    FEB    MAR    APR    MAY    JUN    JUL    AUG    SEP    OCT    NOV    DEC  SUM OR AV.

MEAN TEMP    9.6   11.6   16.5   20.8   25.5   29.5   28.0   26.8   23.8   19.7   14.2    8.2      19.5
MEAN RS     370.   450.   520.   540.   540.   550.   480.   490.   460.   430.   400.   350.      465.
PRECIP        7.     6.    14.     9.    25.    63.   109.   251.   255.     7.    21.    72.      841.
PREC DEP      0.     0.     0.     0.     7.    34.    67.   166.   169.     0.     5.    40.      637.
POT ET       72.    85.   127.   144.   169.   182.   159.   157.   133.   115.    88.    64.     1495.
PREC DEF     72.    85.   127.   144.   161.   148.    92.    -8.   -36.   115.    83.    24.      859.
MAI          .00    .00    .00    .00    .04    .15    .42   1.05   1.27    .00    .05    .63       .43
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      MADERA                      YRS 15   ALT 2078 METERS    LAT 29 17    LON 107 52

             JAN    FEB    MAR    APR    MAY    JUN    JUL    AUG    SEP    OCT    NOV    DEC  SUM OR AV.

MEAN TEMP    6.3    7.4   10.4   12.8   14.6   17.2   17.9   16.4   16.6   13.6    8.7    6.8      12.3
MEAN RS     340.   430.   540.   610.   660.   640.   650.   600.   570.   500.   400.   320.      522.
PRECIP       17.    17.     5.     6.     5.    15.    80.    97.    83.    22.    17.    40.      366.
PREC DEP      2.     2.     0.     0.     0.     1.    46.    58.    20.     5.     2.    18.      209.
POT ET       58.    69.   108.   128.   152.   155.   165.   146.   135.   112.    71.    56.     1356.
PREC DEF     56.    67.   108.   128.   152.   154.   119.    89.   115.   106.    70.    38.     1147.
MAI          .03    .03    .00    .00    .00    .01    .28    .39    .15    .05    .02    .32       .15
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TABLE 3 CLIMATE AND MOISTURE AVAILABILITY INDICES FOR MEXICO

MANUAL DOBLADO YRS 15 ALT 1778 METERS LAT 20 44 LON 101 57

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	SUM OR AV.
MEAN TEMP	15.9	17.5	20.6	22.9	24.8	23.6	22.1	21.8	21.7	20.8	18.2	16.9	20.6
MEAN RS	400.	470.	520.	530.	500.	470.	450.	460.	440.	390.	400.	370.	450.
PRECIP	7.	1.	3.	5.	33.	148.	183.	149.	128.	38.	16.	23.	735.
PREC DEP	0.	0.	0.	0.	13.	94.	118.	94.	79.	17.	1.	6.	542.
POT ET	96.	107.	143.	150.	153.	136.	129.	131.	121.	108.	100.	92.	1466.
PREC DEF	96.	107.	143.	150.	140.	42.	11.	36.	41.	91.	99.	86.	922.
MAI	.00	.00	.00	.00	.09	.69	.91	.72	.66	.16	.01	.07	.27

MANZANILLO YRS 15 ALT 3 METERS LAT 19 4 LON 104 20

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	SUM OR AV.
MEAN TEMP	24.2	23.7	23.6	24.5	26.2	27.8	28.2	28.1	27.6	27.5	26.5	25.2	26.1
MEAN RS	410.	450.	430.	530.	520.	470.	500.	500.	470.	440.	410.	350.	457.
PRECIP	23.	12.	0.	0.	5.	102.	137.	184.	386.	127.	20.	55.	1051.
PREC DEP	6.	0.	0.	0.	0.	62.	86.	119.	260.	79.	4.	28.	825.
POT ET	124.	121.	129.	156.	165.	150.	166.	166.	149.	144.	127.	108.	1702.
PREC DEF	117.	121.	128.	156.	165.	88.	80.	47.	-111.	65.	123.	80.	877.
MAI	.05	.00	.00	.00	.00	.41	.52	.72	1.75	.55	.03	.26	.48

MARAVATIO YRS 15 ALT 2014 METERS LAT 19 53 LON 100 24

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	SUM OR AV.
MEAN TEMP	13.5	14.7	16.8	18.1	19.8	19.5	18.3	18.2	19.4	17.6	15.6	14.2	17.1
MEAN RS	400.	460.	520.	520.	500.	460.	450.	450.	450.	390.	400.	370.	447.
PRECIP	22.	7.	4.	12.	58.	105.	215.	167.	113.	52.	17.	5.	777.
PREC DEP	5.	0.	0.	0.	31.	63.	141.	107.	69.	26.	2.	0.	577.
POT ET	89.	96.	128.	129.	134.	119.	116.	116.	113.	99.	92.	84.	1316.
PREC DEF	84.	96.	128.	129.	103.	55.	-25.	9.	44.	72.	90.	84.	776.
MAI	.06	.00	.00	.00	.23	.53	1.21	.92	.61	.27	.02	.00	.44

MARIA MADRE ISLA YRS 1[illegible] ALT 3 METERS LAT 21 35 LON 106 30

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	SUM OR AV.
MEAN TEMP	20.3	20.3	20.8	22.5	25.2	27.0	28.1	28.1	27.6	26.3	24.5	22.1	24.4
MEAN RS	360.	450.	500.	530.	530.	500.	500.	500.	460.	450.	400.	340.	460.
PRECIP	11.	21.	1.	0.	0.	38.	89.	118.	210.	75.	28.	77.	667.
PREC DEP	0.	4.	0.	0.	0.	16.	52.	73.	137.	42.	10.	44.	490.
POT ET	98.	111.	138.	148.	164.	156.	166.	166.	146.	143.	119.	97.	1650.
PREC DEF	98.	106.	138.	148.	164.	140.	113.	93.	9.	100.	108.	53.	1170.
MAI	.00	.04	.00	.00	.00	.10	.32	.44	.94	.30	.08	.45	.22

MARTIN DON YRS 15 ALT 239 METERS LAT 27 30 LON 100 48

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	SUM OR AV.
MEAN TEMP	12.9	15.3	19.1	23.8	27.1	29.7	30.7	30.7	28.1	23.9	17.9	12.8	22.7
MEAN RS	300.	390.	450.	550.	550.	600.	620.	560.	490.	420.	370.	280.	465.
PRECIP	28.	20.	21.	43.	50.	49.	32.	39.	86.	50.	19.	25.	461.
PREC DEP	10.	4.	4.	20.	25.	24.	12.	17.	50.	25.	3.	7.	295.
POT ET	65.	83.	119.	159.	178.	199.	217.	196.	157.	126.	91.	61.	1652.
PREC DEF	56.	79.	114.	139.	153.	175.	205.	179.	107.	101.	88.	54.	1357.
MAI	.15	.05	.04	.13	.14	.12	.06	.09	.32	.20	.03	.12	.18

MASCOTA YRS 15 ALT 1200 METERS LAT 20 33 LON 104 45

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	SUM OR AV.
MEAN TEMP	18.4	18.8	20.9	23.2	23.8	24.7	23.1	22.8	23.2	22.5	20.7	19.2	21.8
MEAN RS	390.	440.	500.	530.	530.	480.	500.	490.	450.	440.	400.	350.	458.
PRECIP	21.	13.	2.	2.	26.	130.	209.	161.	139.	63.	17.	13.	794.
PREC DEP	5.	0.	0.	0.	8.	81.	136.	103.	87.	34.	2.	0.	594.
POT ET	101.	104.	139.	151.	158.	142.	147.	143.	128.	127.	107.	93.	1539.
PREC DEF	96.	104.	139.	151.	150.	61.	11.	40.	41.	93.	105.	93.	995.
MAI	.05	.00	.00	.00	.05	.57	.93	.72	.68	.27	.02	.00	.39

TABLE 3 CLIMATE AND MOISTURE AVAILABILITY INDICES FOR MEXICO

MATAMOROS YRS 15 ALT 1120 METERS LAT 25 32 LON 103 15

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	SUM OR AV.
MEAN TEMP	12.4	15.8	19.1	23.3	27.0	28.5	26.9	27.6	26.0	23.5	16.5	13.4	21.7
MEAN RS	350.	460.	510.	550.	560.	600.	530.	540.	490.	420.	360.	340.	478.
PRECIP	14.	4.	1.	5.	12.	38.	55.	24.	37.	23.	14.	12.	239.
PREC DEP	0.	0.	0.	0.	0.	17.	28.	7.	16.	6.	0.	0.	95.
POT ET	75.	99.	131.	157.	181.	194.	171.	177.	152.	125.	86.	75.	1623.
PREC DEF	75.	99.	131.	157.	181.	177.	143.	170.	136.	119.	86.	75.	1528.
MAI	.00	.00	.00	.00	.00	.09	.16	.04	.10	.05	.00	.00	.06

MATAMOROS YRS 15 ALT 11 METERS LAT 25 52 LON 97 30

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	SUM OR AV.
MEAN TEMP	16.2	17.9	20.1	23.8	26.5	28.5	29.0	29.3	27.6	24.6	20.1	16.3	23.3
MEAN RS	300.	340.	440.	500.	550.	570.	600.	530.	470.	420.	320.	280.	443.
PRECIP	42.	31.	24.	46.	77.	80.	58.	44.	171.	78.	47.	47.	707.
PREC DEP	19.	12.	10.	22.	41.	46.	31.	21.	110.	45.	23.	23.	852.
POT ET	73.	78.	119.	145.	175.	184.	203.	180.	149.	124.	84.	68.	1597.
PREC DEF	54.	67.	110.	122.	134.	139.	172.	160.	39.	93.	61.	45.	1035.
MAI	.27	.15	.08	.15	.24	.25	.15	.12	.74	.35	.28	.34	.35

MAZATLAN YRS 15 ALT 78 METERS LAT 23 11 LON 106 25

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	SUM OR AV.
MEAN TEMP	19.3	19.4	19.7	21.3	23.9	26.4	27.5	27.6	27.5	26.7	23.5	20.6	23.6
MEAN RS	350.	450.	500.	540.	540.	550.	490.	490.	450.	440.	400.	340.	462.
PRECIP	11.	10.	4.	0.	2.	29.	167.	242.	268.	61.	12.	44.	850.
PREC DEP	0.	0.	0.	0.	0.	10.	107.	159.	178.	33.	0.	21.	645.
POT ET	93.	108.	134.	146.	161.	169.	160.	160.	142.	141.	119.	94.	1629.
PREC DEF	93.	108.	134.	146.	161.	159.	52.	1.	-36.	108.	115.	72.	990.
MAI	.00	.00	.00	.00	.00	.06	.67	.99	1.25	.23	.00	.23	.40

MENDEZ YRS 15 ALT 124 METERS LAT 25 7 LON 98 34

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	SUM OR AV.
MEAN TEMP	15.1	18.6	21.4	25.2	27.8	29.2	29.5	29.9	28.3	25.7	20.0	15.8	23.9
MEAN RS	300.	350.	440.	480.	550.	590.	600.	490.	470.	420.	310.	350.	446.
PRECIP	36.	19.	18.	19.	108.	88.	53.	46.	103.	69.	40.	11.	609.
PREC DEP	15.	4.	3.	2.	66.	52.	27.	23.	62.	39.	18.	0.	428.
POT ET	70.	82.	124.	144.	181.	194.	205.	169.	151.	132.	81.	64.	1616.
PREC DEF	55.	79.	121.	141.	115.	142.	179.	146.	89.	93.	63.	64.	1188.
MAI	.21	.04	.02	.02	.36	.27	.13	.13	.41	.29	.22	.00	.27

MERIDA YRS 15 ALT 21 METERS LAT 20 58 LON 89 39

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	SUM OR AV.
MEAN TEMP	22.9	23.8	25.4	27.1	28.0	27.7	27.4	27.4	27.2	26.1	24.0	23.4	25.9
MEAN RS	350.	430.	500.	450.	450.	500.	490.	500.	440.	400.	390.	330.	442.
PRECIP	31.	16.	19.	26.	81.	151.	141.	129.	154.	102.	31.	30.	913.
PREC DEP	12.	1.	4.	8.	47.	95.	89.	80.	98.	62.	12.	11.	702.
POT ET	102.	116.	155.	154.	162.	159.	160.	163.	138.	126.	113.	98.	1646.
PREC DEF	91.	115.	152.	145.	115.	63.	71.	83.	40.	65.	101.	87.	944.
MAI	.11	.01	.02	.06	.29	.60	.56	.49	.71	.49	.11	.11	.43

MEXICALI YRS 15 ALT 0 METERS LAT 32 39 LON 115 30

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	SUM OR AV.
MEAN TEMP	11.8	15.1	17.9	21.2	25.7	29.6	33.0	32.7	29.5	23.2	16.6	12.3	22.7
MEAN RS	300.	390.	500.	650.	630.	700.	650.	620.	550.	410.	350.	300.	503.
PRECIP	6.	10.	5.	6.	1.	1.	3.	8.	7.	8.	9.	14.	78.
PREC DEP	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
POT ET	63.	80.	127.	176.	195.	232.	239.	227.	182.	121.	83.	64.	1790.
PREC DEF	63.	80.	127.	176.	195.	232.	239.	227.	182.	121.	83.	64.	1790.
MAI	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00

TABLE 3 CLIMATE AND MOISTURE AVAILABILITY INDICES FOR MEXICO

MEXICO CITY YRS 15 ALT 2303 METERS LAT 19 26 LON 99 8

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	SUM OR AV.
MEAN TEMP	12.3	13.9	16.0	17.7	18.3	17.6	16.7	16.7	16.2	15.0	13.7	12.4	15.5
MEAN RS	360.	460.	510.	510.	500.	450.	440.	450.	440.	390.	380.	370.	438.
PRECIP	5.	6.	9.	13.	52.	104.	125.	103.	117.	35.	14.	16.	599.
PREC DEP	0.	0.	0.	0.	26.	63.	78.	62.	72.	14.	0.	1.	419.
POT ET	77.	94.	123.	125.	129.	110.	108.	111.	103.	91.	82.	79.	1233.
PREC DEF	77.	94.	123.	125.	103.	47.	31.	49.	31.	77.	82.	78.	814.
MAI	.00	.00	.00	.00	.20	.57	.72	.56	.70	.16	.00	.02	.34

MEZCALA ISLA YRS 15 ALT 1078 METERS LAT 20 20 LON 103 1

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	SUM OR AV.
MEAN TEMP	18.3	19.7	21.7	23.7	24.7	23.2	22.3	21.9	21.5	21.6	20.2	18.6	21.5
MEAN RS	400.	470.	500.	530.	520.	490.	440.	480.	450.	420.	400.	360.	454.
PRECIP	10.	5.	4.	1.	17.	186.	191.	227.	236.	61.	14.	47.	1001.
PREC DEP	0.	0.	0.	0.	2.	120.	124.	149.	155.	33.	0.	23.	781.
POT ET	103.	114.	142.	153.	159.	137.	127.	137.	123.	119.	105.	94.	1511.
PREC DEF	103.	114.	142.	153.	157.	16.	3.	-12.	-33.	86.	105.	70.	730.
MAI	.00	.00	.00	.00	.01	.88	.98	1.09	1.27	.28	.00	.25	.52

MIAHUATLAN YRS 15 ALT 0 METERS LAT 18 5 LON 97 40

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	SUM OR AV.
MEAN TEMP	18.3	19.0	20.4	21.7	22.3	21.9	21.3	21.3	21.1	20.3	18.9	18.5	20.4
MEAN RS	400.	450.	510.	500.	470.	430.	440.	450.	430.	390.	360.	340.	430.
PRECIP	1.	0.	2.	17.	56.	127.	101.	66.	119.	28.	2.	7.	526.
PREC DEP	0.	0.	0.	2.	29.	79.	61.	36.	73.	10.	0.	0.	353.
POT ET	103.	107.	139.	137.	135.	118.	123.	126.	116.	104.	91.	88.	1389.
PREC DEF	103.	107.	139.	135.	106.	40.	62.	90.	43.	94.	91.	88.	1036.
MAI	.00	.00	.00	.01	.22	.67	.49	.29	.63	.09	.00	.00	.25

MINAS NUEVAS YRS 15 ALT 0 METERS LAT 27 5 LON 109 59

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	SUM OR AV.
MEAN TEMP	16.2	17.2	19.2	22.0	24.7	28.2	27.7	26.4	26.1	24.5	20.6	17.0	22.5
MEAN RS	350.	400.	520.	600.	650.	640.	610.	460.	550.	460.	400.	330.	497.
PRECIP	30.	26.	3.	2.	5.	33.	189.	172.	116.	39.	14.	80.	707.
PREC DEP	11.	8.	0.	0.	0.	13.	122.	111.	71.	18.	0.	46.	516.
POT ET	85.	90.	139.	166.	199.	206.	200.	146.	168.	140.	106.	82.	1726.
PREC DEF	74.	82.	139.	166.	199.	193.	78.	36.	97.	122.	106.	36.	1210.
MAI	.13	.09	.00	.00	.00	.06	.61	.76	.42	.13	.00	.56	.30

MINATITLAN YRS 15 ALT 64 METERS LAT 17 59 LON 94 30

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	SUM OR AV.
MEAN TEMP	23.2	23.9	25.1	27.1	28.9	28.2	27.7	27.5	27.5	26.7	24.6	23.9	26.2
MEAN RS	350.	470.	410.	430.	450.	390.	420.	440.	380.	400.	350.	340.	399.
PRECIP	162.	79.	39.	36.	78.	307.	296.	358.	602.	401.	367.	152.	2876.
PREC DEP	103.	45.	18.	15.	45.	205.	197.	240.	411.	271.	247.	96.	2469.
POT ET	103.	116.	126.	135.	152.	125.	138.	144.	120.	128.	103.	102.	1493.
PREC DEF	-0.	71.	109.	119.	107.	-79.	-59.	-97.	-291.	-142.	-144.	6.	-976.
MAI	1.00	.39	.14	.11	.29	1.63	1.43	1.67	3.42	2.11	2.39	.95	1.65

MISANTLA YRS 15 ALT 410 METERS LAT 19 56 LON 96 51

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	SUM OR AV.
MEAN TEMP	16.4	18.9	20.0	22.4	25.0	25.6	24.9	24.7	24.3	23.5	20.9	17.1	22.0
MEAN RS	340.	400.	440.	470.	510.	450.	450.	460.	440.	400.	340.	330.	418.
PRECIP	53.	120.	96.	88.	89.	136.	173.	136.	229.	246.	198.	121.	1675.
PREC DEP	27.	74.	57.	52.	52.	85.	111.	85.	151.	162.	121.	75.	1387.
POT ET	83.	95.	119.	131.	154.	136.	138.	141.	129.	119.	91.	82.	1417.
PREC DEF	56.	20.	62.	79.	102.	51.	27.	55.	-22.	-44.	-30.	7.	30.
MAI	.33	.78	.48	.39	.34	.62	.81	.61	1.17	1.37	1.33	.91	.98

TABLE 3 CLIMATE AND MOISTURE AVAILABILITY INDICES FOR MEXICO

MIXQUIAHUALA YRS 15 ALT 2050 METERS LAT 20 13 LON 99 13

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	SUM OR AV.
MEAN TEMP	12.6	14.8	16.0	18.2	19.9	19.5	18.4	18.0	18.3	16.2	15.0	14.1	16.7
MEAN RS	360.	450.	500.	510.	500.	470.	450.	460.	450.	390.	380.	350.	439.
PRECIP	11.	9.	11.	17.	62.	74.	106.	99.	104.	46.	10.	6.	554.
PREC DEP	0.	0.	0.	2.	33.	42.	64.	58.	63.	23.	0.	0.	378.
POT ET	78.	94.	120.	127.	135.	118.	116.	118.	112.	95.	86.	79.	1279.
PREC DEF	78.	94.	120.	126.	102.	76.	52.	59.	50.	72.	86.	79.	901.
MAI	.00	.00	.00	.01	.25	.36	.55	.50	.56	.24	.00	.00	.30

MOCORITO YRS 15 ALT 838 METERS LAT 25 29 LON 107 55

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	SUM OR AV.
MEAN TEMP	18.4	19.3	20.7	23.3	26.2	29.6	29.8	28.8	28.2	25.6	22.6	19.1	24.3
MEAN RS	350.	410.	500.	580.	570.	600.	550.	500.	500.	450.	400.	330.	478.
PRECIP	10.	20.	11.	2.	1.	38.	215.	163.	115.	42.	20.	97.	734.
PREC DEP	0.	4.	0.	0.	0.	17.	140.	108.	73.	20.	4.	51.	541.
POT ET	91.	98.	138.	165.	181.	199.	189.	168.	161.	141.	112.	87.	1729.
PREC DEF	91.	94.	138.	165.	181.	182.	49.	60.	87.	121.	108.	76.	1188.
MAI	.00	.04	.00	.00	.00	.08	.74	.64	.46	.14	.04	.58	.31

MOLINOS DE CABALLERO YRS 15 ALT 0 METERS LAT 20 3 LON 100 10

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	SUM OR AV.
MEAN TEMP	11.1	12.2	14.4	15.8	17.3	16.9	15.9	16.1	15.9	14.4	12.9	11.9	14.6
MEAN RS	390.	460.	510.	520.	500.	460.	440.	460.	440.	390.	380.	350.	442.
PRECIP	18.	11.	12.	29.	31.	183.	185.	156.	193.	53.	36.	26.	924.
PREC DEP	3.	0.	0.	10.	12.	118.	119.	99.	118.	27.	15.	8.	712.
POT ET	80.	89.	117.	120.	125.	110.	106.	111.	102.	89.	80.	76.	1206.
PREC DEF	77.	89.	117.	110.	113.	-8.	-14.	12.	-16.	63.	65.	67.	494.
MAI	.03	.00	.00	.09	.09	1.07	1.13	.89	1.16	.30	.19	.11	.59

MONCLOVA YRS 15 ALT 585 METERS LAT 26 55 LON 101 26

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	SUM OR AV.
MEAN TEMP	12.6	15.2	18.2	22.3	25.5	27.7	27.7	28.1	25.1	21.8	16.7	12.8	21.1
MEAN RS	310.	380.	470.	550.	550.	620.	590.	550.	490.	420.	330.	290.	462.
PRECIP	15.	15.	8.	18.	35.	36.	53.	30.	108.	35.	17.	15.	386.
PREC DEP	1.	1.	0.	2.	15.	15.	27.	11.	66.	14.	2.	1.	227.
POT ET	67.	81.	121.	153.	171.	197.	194.	182.	146.	119.	79.	63.	1573.
PREC DEF	66.	80.	121.	151.	157.	182.	167.	171.	80.	105.	77.	62.	1346.
MAI	.01	.01	.00	.01	.09	.08	.14	.06	.45	.12	.02	.01	.14

MONTE MORELOS YRS 15 ALT 432 METERS LAT 25 12 LON 99 50

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	SUM OR AV.
MEAN TEMP	15.5	17.2	24.1	25.7	28.3	28.7	30.7	29.9	27.8	25.2	20.2	15.3	24.1
MEAN RS	300.	420.	440.	530.	550.	590.	600.	540.	470.	420.	310.	280.	454.
PRECIP	11.	10.	19.	23.	84.	83.	7.	10.	71.	39.	24.	11.	398.
PREC DEP	0.	0.	3.	6.	48.	48.	0.	2.	39.	17.	7.	0.	238.
POT ET	71.	95.	133.	161.	183.	192.	210.	186.	150.	130.	82.	66.	1657.
PREC DEF	71.	95.	130.	155.	134.	144.	210.	184.	110.	112.	75.	66.	1419.
MAI	.00	.00	.02	.04	.27	.25	.00	.01	.26	.13	.08	.00	.14

MONTE PUERTA YRS 15 ALT 1700 METERS LAT 20 14 LON 101 1

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	SUM OR AV.
MEAN TEMP	13.9	14.9	17.9	18.8	20.9	21.2	19.8	20.0	19.8	18.1	16.1	14.6	18.0
MEAN RS	400.	470.	510.	530.	500.	470.	450.	460.	440.	390.	400.	370.	449.
PRECIP	8.	4.	5.	8.	32.	52.	153.	137.	135.	52.	25.	8.	619.
PREC DEP	0.	0.	0.	0.	12.	26.	97.	86.	85.	26.	8.	0.	437.
POT ET	90.	99.	130.	134.	139.	127.	121.	125.	114.	100.	94.	85.	1358.
PREC DEF	90.	99.	130.	134.	126.	101.	24.	39.	30.	74.	86.	85.	920.
MAI	.00	.00	.00	.00	.09	.21	.81	.69	.74	.26	.08	.00	.32

TABLE 3 CLIMATE AND MOISTURE AVAILABILITY INDICES FOR MEXICO

MORELIA YRS 15 ALT 1922 METERS LAT 19 42 LON 101 7

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	SUM OR AV.
MEAN TEMP	13.9	15.4	17.3	19.2	20.5	19.5	18.2	18.0	17.9	17.1	15.4	14.4	17.2
MEAN RS	400.	470.	500.	520.	500.	450.	450.	460.	450.	400.	400.	380.	448.
PRECIP	13.	8.	7.	8.	43.	132.	171.	160.	155.	58.	19.	6.	781.
PREC DEP	0.	0.	0.	0.	20.	82.	110.	102.	99.	31.	3.	0.	583.
POT ET	90.	100.	125.	133.	137.	116.	116.	118.	111.	100.	92.	87.	1325.
PREC DEF	90.	100.	125.	133.	117.	34.	6.	16.	12.	69.	88.	87.	742.
MAI	.00	.00	.00	.00	.15	.71	.95	.87	.89	.31	.03	.00	.44

MOROLEON YRS 15 ALT 1771 METERS LAT 20 8 LON 101 12

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	SUM OR AV.
MEAN TEMP	16.1	18.0	21.1	23.0	24.1	22.9	21.1	21.1	20.9	19.8	17.9	16.6	20.2
MEAN RS	400.	470.	510.	530.	500.	470.	450.	460.	440.	390.	400.	370.	449.
PRECIP	3.	3.	8.	8.	41.	149.	167.	152.	172.	44.	24.	19.	791.
PREC DEP	0.	0.	0.	0.	19.	94.	107.	97.	111.	21.	7.	3.	592.
POT ET	97.	108.	142.	150.	151.	133.	125.	128.	118.	105.	99.	91.	1447.
PREC DEF	97.	108.	142.	150.	132.	38.	18.	32.	7.	84.	92.	88.	855.
MAI	.00	.00	.00	.00	.13	.71	.85	.75	.94	.20	.07	.03	.41

MOTOZINTLA YRS 15 ALT 1454 METERS LAT 15 22 LON 92 14

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	SUM OR AV.
MEAN TEMP	19.4	20.4	21.4	23.1	23.4	22.3	22.2	22.1	21.8	21.3	19.8	20.0	21.4
MEAN RS	350.	470.	520.	470.	450.	380.	410.	400.	370.	400.	450.	400.	422.
PRECIP	0.	1.	3.	9.	63.	189.	121.	116.	140.	86.	9.	3.	741.
PREC DEP	0.	0.	0.	0.	34.	122.	75.	71.	88.	50.	0.	0.	547.
POT ET	93.	116.	145.	134.	133.	106.	118.	115.	102.	112.	117.	108.	1399.
PREC DEF	93.	116.	145.	134.	99.	-17.	43.	44.	13.	61.	117.	108.	852.
MAI	.00	.00	.00	.00	.26	1.16	.64	.62	.87	.45	.00	.00	.39

MULEGE YRS 15 ALT 35 METERS LAT 26 53 LON 112 0

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	SUM OR AV.
MEAN TEMP	14.0	16.0	17.9	20.1	22.9	27.2	30.5	30.4	29.0	24.6	19.5	14.9	22.7
MEAN RS	350.	400.	500.	560.	610.	630.	620.	550.	510.	450.	390.	300.	489.
PRECIP	3.	4.	0.	0.	0.	0.	6.	17.	40.	5.	7.	19.	101.
PREC DEP	0.	0.	0.	0.	0.	0.	0.	2.	18.	0.	0.	4.	0.
POT ET	79.	87.	127.	147.	178.	198.	216.	191.	167.	137.	101.	70.	1699.
PREC DEF	79.	87.	127.	147.	178.	198.	216.	190.	149.	137.	101.	66.	1699.
MAI	.00	.00	.00	.00	.00	.00	.00	.01	.11	.00	.00	.05	.00

MUZQUIZ YRS 15 ALT 503 METERS LAT 27 52 LON 101 31

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	SUM OR AV.
MEAN TEMP	15.1	16.5	18.7	23.5	25.7	28.4	29.8	29.3	27.4	24.0	17.9	13.4	22.4
MEAN RS	300.	390.	450.	550.	550.	620.	610.	560.	500.	470.	310.	280.	462.
PRECIP	24.	11.	26.	27.	88.	78.	63.	78.	177.	72.	28.	27.	702.
PREC DEP	7.	0.	9.	9.	52.	45.	34.	45.	114.	41.	10.	9.	511.
POT ET	70.	86.	118.	158.	172.	200.	205.	190.	158.	126.	76.	62.	1622.
PREC DEF	63.	86.	109.	149.	120.	155.	171.	146.	44.	86.	67.	53.	1111.
MAI	.10	.00	.07	.05	.30	.22	.17	.24	.72	.32	.13	.14	.32

NACO YRS 15 ALT 1403 METERS LAT 31 21 LON 109 56

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	SUM OR AV.
MEAN TEMP	7.6	9.6	11.6	14.7	19.3	24.4	24.6	23.1	21.6	17.5	12.2	7.2	16.1
MEAN RS	330.	420.	540.	650.	690.	700.	670.	610.	570.	430.	400.	320.	527.
PRECIP	12.	23.	14.	7.	4.	15.	98.	83.	52.	19.	21.	30.	388.
PREC DEP	0.	13.	0.	0.	0.	1.	58.	48.	26.	3.	5.	11.	229.
POT ET	59.	74.	113.	146.	183.	205.	204.	179.	156.	108.	83.	57.	1566.
PREC DEF	59.	61.	113.	146.	183.	204.	146.	131.	130.	105.	78.	45.	1337.
MAI	.00	.17	.00	.00	.00	.00	.29	.27	.17	.03	.06	.20	.15

TABLE 3 CLIMATE AND MOISTURE AVAILABILITY INDICES FOR MEXICO

NAUTLA YRS 15 ALT 7 METERS LAT 20 15 LON 96 47

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	SUM OR AV.
MEAN TEMP	22.7	23.8	24.8	27.7	28.8	29.0	29.1	29.2	28.8	27.9	25.7	23.9	26.8
MEAN RS	330.	410.	460.	500.	500.	480.	460.	470.	450.	400.	400.	320.	432.
PRECIP	75.	51.	47.	35.	81.	152.	258.	114.	430.	364.	89.	121.	1816.
PREC DEP	42.	26.	23.	15.	46.	96.	170.	69.	291.	245.	52.	75.	1514.
POT ET	96.	111.	141.	159.	168.	157.	156.	160.	146.	131.	121.	96.	1642.
PREC DEF	53.	85.	118.	144.	122.	61.	-14.	90.	-145.	-113.	69.	21.	128.
MAT	.44	.23	.16	.09	.28	.61	1.09	.44	1.99	1.86	.43	.78	.92

NAVOJOA YRS 15 ALT 38 METERS LAT 27 7 LON 109 28

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	SUM OR AV.
MEAN TEMP	17.9	19.4	20.8	23.8	27.0	31.2	33.8	32.4	31.9	29.0	23.3	19.3	25.8
MEAN RS	360.	470.	530.	600.	650.	660.	620.	590.	560.	530.	390.	320.	520.
PRECIP	3.	1.	4.	0.	10.	6.	73.	100.	56.	57.	14.	72.	396.
PREC DEP	0.	0.	0.	0.	0.	0.	41.	60.	29.	30.	0.	41.	237.
POT ET	92.	103.	146.	174.	210.	227.	232.	214.	195.	179.	111.	85.	1967.
PREC DEF	92.	103.	146.	174.	210.	227.	191.	154.	166.	149.	111.	44.	1731.
MAT	.00	.00	.00	.00	.00	.00	.18	.28	.15	.17	.00	.48	.12

NAZAS YRS 15 ALT 1275 METERS LAT 25 13 LON 104 8

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	SUM OR AV.
MEAN TEMP	13.6	16.4	19.0	22.6	25.9	27.5	26.2	26.0	24.7	21.9	17.0	14.0	21.2
MEAN RS	350.	460.	520.	550.	560.	600.	540.	530.	500.	440.	390.	350.	482.
PRECIP	8.	5.	3.	5.	20.	36.	78.	61.	56.	22.	9.	10.	314.
PREC DEP	0.	0.	0.	0.	4.	15.	45.	33.	29.	6.	0.	0.	163.
POT ET	78.	101.	137.	154.	176.	190.	171.	167.	148.	125.	94.	79.	1621.
PREC DEF	78.	101.	137.	154.	172.	174.	126.	134.	119.	119.	94.	79.	1458.
MAT	.00	.00	.00	.00	.02	.08	.26	.20	.20	.05	.00	.00	.10

NUEVO LAREDO YRS 15 ALT 139 METERS LAT 27 29 LON 99 30

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	SUM OR AV.
MEAN TEMP	14.1	17.8	20.8	25.2	28.1	30.4	32.5	32.3	29.9	26.5	21.0	16.1	24.6
MEAN RS	290.	370.	430.	500.	500.	600.	620.	560.	480.	420.	300.	270.	445.
PRECIP	24.	24.	21.	26.	64.	41.	29.	20.	78.	28.	27.	26.	407.
PREC DEP	7.	7.	4.	8.	35.	19.	10.	4.	45.	9.	9.	8.	247.
POT ET	66.	85.	119.	150.	166.	202.	226.	203.	160.	134.	81.	65.	1655.
PREC DEF	59.	78.	114.	141.	131.	183.	215.	199.	115.	125.	72.	57.	1409.
MAT	.10	.08	.04	.06	.21	.09	.05	.02	.28	.07	.11	.13	.15

OAXACA YRS 15 ALT 1563 METERS LAT 17 4 LON 96 42

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	SUM OR AV.
MEAN TEMP	17.5	19.0	21.0	22.4	22.7	21.4	20.9	20.9	20.3	19.7	18.4	18.0	20.2
MEAN RS	350.	450.	480.	450.	460.	400.	430.	450.	400.	370.	350.	350.	412.
PRECIP	2.	2.	11.	24.	62.	125.	93.	103.	169.	40.	8.	9.	650.
PREC DEP	0.	0.	0.	7.	34.	78.	55.	62.	108.	18.	0.	0.	465.
POT ET	88.	107.	133.	126.	134.	109.	119.	124.	106.	99.	68.	99.	1322.
PREC DEF	88.	107.	133.	118.	100.	31.	64.	62.	-3.	81.	68.	99.	857.
MAT	.00	.00	.00	.06	.25	.71	.47	.50	1.03	.18	.00	.00	.35

OBREGON YRS 15 ALT 39 METERS LAT 27 29 LON 109 55

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	SUM OR AV.
MEAN TEMP	18.2	19.8	22.2	25.2	27.4	32.1	33.6	33.7	32.7	29.2	23.8	19.6	26.5
MEAN RS	360.	400.	530.	600.	650.	650.	620.	590.	560.	510.	390.	320.	515.
PRECIP	7.	5.	2.	4.	0.	2.	70.	46.	44.	14.	4.	13.	212.
PREC DEP	0.	0.	0.	0.	0.	0.	39.	23.	21.	0.	0.	0.	70.
POT ET	93.	97.	152.	180.	212.	227.	231.	220.	198.	173.	113.	86.	1982.
PREC DEF	93.	97.	152.	180.	212.	227.	192.	198.	178.	173.	113.	86.	1912.
MAT	.00	.00	.00	.00	.00	.00	.17	.10	.11	.00	.00	.00	.04

TABLE 3 CLIMATE AND MOISTURE AVAILABILITY INDICES FOR MEXICO

OCAMPO YRS 15 ALT 1238 METERS LAT 21 38 LON 101 24

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	SUM OR AV.
MEAN TEMP	12.6	14.2	16.4	18.3	21.4	20.0	18.9	19.2	18.5	16.9	14.6	13.9	17.1
MEAN RS	400.	460.	510.	530.	500.	490.	450.	460.	450.	390.	390.	360.	448.
PRECIP	21.	8.	10.	6.	29.	81.	104.	88.	91.	23.	20.	18.	498.
PREC DEP	4.	0.	0.	0.	11.	46.	63.	52.	54.	6.	4.	3.	329.
POT ET	87.	95.	124.	132.	140.	126.	119.	122.	113.	97.	87.	81.	1322.
PREC DEF	92.	95.	124.	132.	130.	79.	55.	70.	59.	91.	83.	78.	993.
MAI	.05	.00	.00	.00	.08	.37	.53	.42	.48	.06	.05	.03	.25

OCOSINGO YRS 15 ALT 770 METERS LAT 17 2 LON 92 11

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	SUM OR AV.
MEAN TEMP	21.9	22.7	23.2	25.2	26.3	25.9	25.6	25.8	25.8	24.6	22.2	21.8	24.2
MEAN RS	340.	440.	480.	420.	450.	430.	400.	460.	350.	400.	400.	340.	409.
PRECIP	41.	42.	37.	78.	180.	252.	209.	184.	286.	83.	55.	68.	1515.
PREC DEP	19.	20.	16.	45.	116.	166.	136.	119.	190.	49.	28.	37.	1244.
POT ET	97.	116.	141.	126.	143.	131.	125.	144.	106.	122.	111.	97.	1458.
PREC DEF	78.	96.	125.	81.	27.	-35.	-11.	26.	-84.	74.	83.	59.	214.
MAI	.20	.17	.11	.36	.81	1.27	1.09	.82	1.79	.40	.25	.39	.85

OJINAGA YRS 15 ALT 840 METERS LAT 29 34 LON 104 25

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	SUM OR AV.
MEAN TEMP	12.2	15.7	15.9	21.1	25.7	30.8	30.7	30.6	27.8	23.0	14.9	10.8	21.6
MEAN RS	330.	450.	540.	600.	630.	630.	590.	580.	550.	440.	360.	300.	500.
PRECIP	3.	6.	4.	3.	9.	12.	27.	44.	41.	32.	14.	12.	208.
PREC DEP	0.	0.	0.	0.	0.	0.	9.	21.	19.	12.	0.	0.	67.
POT ET	70.	97.	129.	162.	197.	214.	205.	203.	175.	129.	81.	61.	1723.
PREC DEF	70.	97.	129.	162.	197.	214.	196.	182.	156.	116.	81.	61.	1656.
MAI	.00	.00	.00	.00	.00	.00	.04	.10	.11	.10	.00	.00	.04

OJO EL YRS 15 ALT 2000 METERS LAT 24 9 LON 104 4

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	SUM OR AV.
MEAN TEMP	10.6	11.8	13.8	17.0	19.8	21.8	20.1	19.3	18.7	16.5	12.5	11.6	16.1
MEAN RS	350.	460.	530.	550.	540.	590.	500.	510.	470.	440.	400.	350.	474.
PRECIP	8.	10.	0.	2.	12.	62.	120.	104.	83.	42.	15.	20.	484.
PREC DEP	0.	0.	0.	0.	0.	34.	78.	63.	46.	19.	0.	4.	316.
POT ET	70.	87.	119.	132.	145.	162.	136.	135.	119.	108.	83.	73.	1370.
PREC DEF	70.	87.	119.	132.	145.	128.	57.	72.	71.	89.	83.	69.	1054.
MAI	.00	.00	.00	.00	.00	.21	.58	.46	.41	.18	.01	.05	.23

OMETEPEC YRS 15 ALT 400 METERS LAT 16 33 LON 98 35

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	SUM OR AV.
MEAN TEMP	25.7	26.2	26.8	27.2	28.4	27.4	27.1	27.3	26.8	27.4	27.3	27.5	27.1
MEAN RS	400.	480.	510.	500.	500.	440.	490.	460.	450.	450.	410.	390.	457.
PRECIP	0.	0.	0.	3.	19.	92.	58.	71.	107.	35.	5.	1.	392.
PREC DEP	0.	0.	0.	0.	4.	55.	31.	39.	65.	15.	0.	0.	233.
POT ET	125.	137.	164.	157.	167.	139.	159.	150.	140.	147.	129.	127.	1740.
PREC DEF	125.	137.	164.	157.	163.	84.	128.	110.	75.	132.	129.	127.	1507.
MAI	.00	.00	.00	.00	.02	.39	.19	.26	.46	.10	.00	.00	.13

ORIZABA YRS 15 ALT 1247 METERS LAT 18 51 LON 97 5

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	SUM OR AV.
MEAN TEMP	15.1	16.7	17.9	20.3	21.0	20.1	19.5	19.6	19.5	18.9	16.6	15.7	18.4
MEAN RS	400.	450.	500.	500.	480.	440.	450.	450.	420.	380.	370.	350.	432.
PRECIP	46.	40.	26.	49.	136.	351.	371.	329.	430.	184.	100.	55.	2115.
PREC DEP	22.	18.	8.	24.	85.	236.	249.	220.	291.	119.	60.	28.	1784.
POT ET	94.	99.	127.	132.	133.	116.	120.	120.	108.	100.	88.	84.	1321.
PREC DEF	72.	81.	119.	108.	48.	-120.	-129.	-100.	-182.	-19.	28.	55.	-463.
MAI	.24	.18	.07	.18	.64	2.04	2.08	1.83	2.68	1.19	.68	.34	1.35

TABLE 3 CLIMATE AND MOISTURE AVAILABILITY INDICES FOR MEXICO

ORO EL   YRS 15   ALT 1829 METERS   LAT 25 57   LON 105 20

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	SUM OR AV.
MEAN TEMP	10.6	14.6	16.6	19.0	21.7	22.6	21.3	21.2	20.1	17.6	15.3	10.4	17.6
MEAN RS	350.	460.	510.	540.	550.	600.	600.	510.	500.	440.	400.	350.	484.
PRECIP	3.	2.	2.	8.	7.	50.	134.	198.	200.	47.	16.	9.	676.
PREC DEP	0.	0.	0.	0.	0.	25.	84.	129.	130.	23.	1.	0.	488.
POT ET	70.	96.	125.	137.	156.	158.	168.	143.	131.	111.	91.	70.	1468.
PREC DEF	70.	96.	125.	137.	156.	143.	84.	14.	1.	88.	90.	70.	980.
MAI	.00	.00	.00	.00	.00	.15	.50	.90	.99	.21	.01	.00	.33

ORO EL   YRS 15   ALT 1889 METERS   LAT 19 49   LON 100 5

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	SUM OR AV.
MEAN TEMP	10.5	11.0	13.2	14.2	14.2	13.4	13.4	13.3	13.3	12.5	11.3	10.5	12.6
MEAN RS	390.	460.	500.	510.	500.	450.	450.	450.	450.	400.	400.	370.	444.
PRECIP	9.	11.	7.	12.	38.	90.	170.	191.	136.	56.	27.	7.	755.
PREC DEP	0.	0.	0.	0.	16.	53.	109.	124.	85.	29.	9.	0.	559.
POT ET	78.	85.	110.	112.	114.	97.	100.	99.	96.	86.	80.	74.	1132.
PREC DEF	78.	85.	110.	112.	98.	43.	-9.	-24.	11.	57.	71.	74.	573.
MAI	.00	.00	.00	.00	.14	.55	1.09	1.25	.89	.34	.11	.00	.49

OZULUAMA   YRS 15   ALT 228 METERS   LAT 21 40   LON 97 51

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	SUM OR AV.
MEAN TEMP	18.4	20.2	22.1	25.2	27.3	27.8	27.3	27.5	26.5	25.2	21.9	18.8	24.0
MEAN RS	350.	450.	450.	550.	520.	500.	470.	480.	460.	400.	350.	320.	442.
PRECIP	46.	20.	14.	23.	82.	246.	218.	191.	388.	234.	53.	42.	1558.
PREC DEP	23.	4.	0.	6.	47.	162.	142.	124.	262.	154.	27.	20.	1282.
POT ET	91.	111.	129.	165.	169.	159.	153.	157.	142.	124.	96.	84.	1578.
PREC DEF	68.	107.	129.	158.	122.	-3.	10.	33.	-120.	-30.	69.	64.	296.
MAI	.25	.04	.00	.04	.29	1.02	.93	.79	1.84	1.24	.28	.24	.81

PACHUCA   YRS 15   ALT 2435 METERS   LAT 20 8   LON 98 45

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	SUM OR AV.
MEAN TEMP	11.8	12.8	14.5	15.9	16.7	15.8	15.2	15.1	14.9	13.5	12.2	12.4	14.2
MEAN RS	360.	460.	500.	500.	500.	480.	450.	470.	450.	390.	350.	350.	438.
PRECIP	5.	13.	13.	18.	33.	72.	59.	53.	78.	49.	21.	6.	420.
PREC DEP	0.	0.	0.	3.	13.	40.	31.	27.	45.	24.	4.	0.	258.
POT ET	76.	90.	115.	116.	123.	111.	106.	110.	101.	87.	77.	75.	1183.
PREC DEF	76.	90.	115.	114.	110.	71.	75.	83.	57.	63.	69.	75.	925.
MAI	.00	.00	.00	.02	.11	.36	.29	.25	.44	.28	.06	.00	.22

PALENQUE   YRS 15   ALT 210 METERS   LAT 17 30   LON 92 0

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	SUM OR AV.
MEAN TEMP	21.7	25.6	26.2	27.1	29.6	28.8	27.7	27.7	27.2	26.1	25.0	23.7	26.4
MEAN RS	340.	450.	500.	420.	450.	430.	400.	450.	350.	400.	400.	340.	411.
PRECIP	276.	171.	84.	25.	132.	305.	316.	351.	485.	614.	262.	215.	3187.
PREC DEP	183.	75.	49.	8.	83.	203.	211.	236.	329.	420.	174.	140.	2748.
POT ET	96.	127.	159.	132.	154.	140.	131.	148.	110.	126.	119.	101.	1544.
PREC DEF	-87.	52.	109.	124.	72.	-64.	-80.	-89.	-219.	-293.	-55.	-39.	-1205.
MAI	1.90	.59	.31	.06	.54	1.45	1.61	1.60	3.00	3.32	1.46	1.38	1.78

PANUCO   YRS 15   ALT 602 METERS   LAT 23 24   LON 105 58

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	SUM OR AV.
MEAN TEMP	20.4	21.1	23.1	25.1	27.6	27.2	26.0	25.9	25.7	24.2	22.1	20.2	24.0
MEAN RS	370.	460.	510.	540.	540.	550.	480.	490.	450.	430.	400.	350.	464.
PRECIP	7.	12.	9.	0.	0.	132.	412.	231.	244.	153.	10.	68.	1279.
PREC DEP	0.	0.	0.	0.	0.	82.	279.	152.	161.	97.	0.	37.	1031.
POT ET	101.	116.	150.	161.	176.	173.	151.	154.	135.	130.	111.	95.	1653.
PREC DEF	101.	116.	150.	161.	176.	91.	-127.	2.	-26.	33.	111.	58.	622.
MAI	.00	.00	.00	.00	.00	.48	1.84	.99	1.20	.75	.00	.39	.62

TABLE 3 CLIMATE AND MOISTURE AVAILABILITY INDICES FOR MEXICO

PATZCUARO YRS 15 ALT 2138 METERS LAT 19 30 LON 101 31

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	SUM OR AV.
MEAN TEMP	13.9	13.3	16.1	17.9	19.9	19.2	17.3	17.0	16.8	16.0	14.3	12.5	16.7
MEAN RS	400.	470.	510.	510.	500.	460.	450.	460.	450.	400.	400.	380.	449.
PRECIP	21.	19.	7.	4.	38.	199.	246.	239.	214.	78.	26.	23.	1110.
PREC DEP	4.	0.	0.	0.	17.	129.	162.	157.	140.	45.	8.	6.	879.
POT ET	90.	94.	123.	126.	135.	118.	113.	114.	107.	96.	88.	82.	1286.
PREC DEF	86.	94.	123.	126.	118.	-11.	-49.	-43.	-32.	52.	80.	76.	408.
MAI	.05	.00	.00	.00	.12	1.10	1.44	1.38	1.30	.46	.09	.07	.68

PENJAMO YRS 15 ALT 1760 METERS LAT 20 26 LON 101 43

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	SUM OR AV.
MEAN TEMP	16.2	17.1	19.4	22.1	22.4	22.4	21.9	21.2	20.6	20.2	18.2	17.0	19.9
MEAN RS	400.	470.	510.	520.	500.	530.	450.	460.	440.	390.	400.	370.	453.
PRECIP	17.	5.	4.	1.	41.	174.	202.	181.	140.	39.	20.	14.	789.
PREC DEP	2.	0.	0.	0.	19.	77.	131.	117.	88.	17.	4.	0.	590.
POT ET	97.	106.	136.	144.	144.	148.	128.	129.	117.	106.	100.	92.	1446.
PREC DEF	95.	106.	136.	144.	125.	71.	-4.	12.	29.	89.	96.	92.	856.
MAI	.02	.00	.00	.00	.13	.52	1.03	.91	.75	.16	.04	.00	.41

PENON BLANCO YRS 15 ALT 1610 METERS LAT 24 47 LON 104 2

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	SUM OP AV.
MEAN TEMP	11.7	13.2	15.1	17.2	20.2	21.8	20.3	20.2	13.3	17.3	13.9	12.3	16.9
MEAN RS	360.	460.	520.	540.	540.	560.	490.	500.	460.	430.	400.	350.	467.
PRECIP	5.	6.	0.	3.	23.	40.	99.	107.	74.	21.	11.	7.	397.
PREC DEP	0.	0.	0.	0.	6.	18.	59.	65.	42.	5.	0.	0.	238.
POT ET	75.	92.	122.	131.	147.	154.	134.	136.	118.	108.	87.	75.	1378.
PREC DEF	75.	92.	122.	131.	141.	136.	74.	71.	76.	103.	87.	75.	1141.
MAI	.00	.00	.00	.00	.04	.12	.44	.48	.36	.04	.00	.00	.17

PEROTE YRS 15 ALT 2464 METERS LAT 19 34 LON 97 15

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	SUM OP V.
MEAN TEMP	10.2	11.3	13.9	15.1	15.7	15.0	14.5	14.7	13.9	12.7	11.2	10.8	13.3
MEAN RS	440.	520.	540.	530.	510.	500.	500.	520.	450.	460.	500.	510.	499.
PREC DEP	0.	1.	0.	4.	7.	53.	17.	11.	66.	52.	8.	0.	312.
POT ET	87.	97.	122.	120.	122.	113.	115.	120.	100.	100.	100.	103.	1300.
PREC DEF	87.	96.	122.	117.	115.	60.	99.	110.	34.	48.	92.	103.	989.
MAI	.00	.01	.00	.03	.06	.47	.15	.09	.66	.52	.09	.00	.24

PIAXTLA YRS 15 ALT 1120 METERS LAT 18 12 LON 98 16

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	SUM OR AV.
MEAN TEMP	21.4	23.2	25.3	26.7	27.4	25.6	24.9	25.1	24.2	23.5	22.2	21.5	24.2
MEAN RS	350.	470.	510.	500.	490.	410.	440.	450.	430.	380.	380.	350.	431.
PREC DEP	0.	0.	0.	0.	26.	101.	84.	75.	113.	24.	0.	0.	578.
POT ET	101.	125.	158.	155.	160.	174.	135.	139.	126.	113.	106.	99.	1539.
PREC DEF	101.	125.	158.	155.	133.	73.	50.	64.	13.	89.	106.	99.	1011.
MAI	.00	.00	.00	.00	.16	.82	.63	.54	.90	.21	.00	.00	.34

PIEDAD LA YRS 15 ALT 1775 METERS LAT 20 20 LON 102 1

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	SUM OR AV.
MEAN TEMP	14.2	15.8	19.1	20.8	22.5	22.7	21.2	21.0	20.6	19.2	16.8	15.1	19.0
MEAN RS	400.	470.	510.	530.	500.	530.	450.	470.	450.	400.	400.	370.	457.
PREC DEP	5.	2.	0.	0.	17.	107.	153.	140.	140.	31.	9.	17.	817.
POT ET	91.	102.	131.	142.	145.	149.	126.	131.	120.	106.	96.	87.	1423.
PREC DEF	86.	100.	131.	142.	127.	42.	-29.	-9.	-21.	75.	97.	70.	606.
MAI	.06	.02	.00	.00	.12	.72	1.22	1.07	1.17	.30	.09	.19	.57

TABLE 3 CLIMATE AND MOISTURE AVAILABILITY INDICES FOR MEXICO

PIEDRAS NEGRAS YRS 15 ALT 220 METERS LAT 28 42 LON 100 31

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	SUM OR AV.
MEAN TEMP	10.9	14.6	17.9	22.2	25.4	28.5	29.9	30.2	27.7	26.6	16.0	10.9	21.7
MEAN RS	300.	380.	440.	550.	550.	610.	630.	570.	500.	420.	300.	270.	460.
PREC DEP	6.	8.	7.	23.	56.	25.	15.	9.	57.	19.	7.	12.	340.
POT ET	61.	79.	112.	153.	171.	197.	217.	198.	159.	134.	70.	55.	1606.
PREC DEF	55.	71.	105.	130.	115.	172.	202.	190.	102.	115.	62.	43.	1266.
MAI	.10	.10	.06	.15	.33	.13	.07	.04	.36	.14	.11	.22	.22

PILARES DE NACOZARI YRS 15 ALT 1408 METERS LAT 30 19 LON 109 43

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	SUM OR AV.
MEAN TEMP	9.5	11.4	13.9	17.0	20.8	25.3	25.1	24.2	24.1	20.2	14.8	10.3	18.0
MEAN RS	340.	470.	540.	610.	670.	700.	650.	600.	500.	480.	400.	370.	524.
PREC DEP	3.	10.	3.	0.	0.	13.	115.	91.	31.	19.	4.	23.	424.
POT ET	66.	79.	122.	147.	185.	210.	200.	181.	163.	131.	90.	64.	1637.
PREC DEF	63.	69.	119.	147.	185.	197.	86.	91.	132.	112.	86.	40.	1213.
MAI	.05	.13	.02	.00	.00	.06	.57	.50	.19	.14	.04	.37	.26

POLOTITLAN YRS 15 ALT 2290 METERS LAT 20 14 LON 99 49

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	SUM OR AV.
MEAN TEMP	11.5	14.1	16.6	17.9	19.6	18.5	18.1	17.8	17.1	15.6	13.8	11.2	16.2
MEAN RS	360.	450.	500.	510.	500.	460.	440.	460.	450.	390.	380.	350.	438.
PREC DEP	0.	0.	1.	10.	26.	114.	88.	47.	84.	19.	6.	0.	523.
POT ET	75.	92.	123.	126.	134.	116.	113.	117.	109.	93.	83.	77.	1258.
PREC DEF	75.	92.	122.	116.	108.	1.	25.	70.	24.	74.	77.	77.	733.
MAI	.00	.00	.01	.08	.19	.99	.78	.40	.77	.21	.07	.00	.42

PROGRESO YRS 15 ALT 14 METERS LAT 21 17 LON 89 40

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	SUM OR AV.
MEAN TEMP	22.7	23.1	24.1	25.5	26.3	26.7	26.7	26.8	26.8	26.3	24.4	23.2	25.2
MEAN RS	340.	430.	490.	520.	500.	510.	500.	500.	450.	410.	380.	330.	447.
PRECIP	33.	17.	15.	18.	55.	73.	45.	46.	55.	69.	20.	26.	473.
PREC DEP	13.	[illegible]	0.	2.	29.	41.	22.	22.	29.	38.	4.	8.	305.
POT ET	99.	114.	149.	157.	159.	158.	160.	160.	140.	130.	112.	97.	1633.
PREC DEF	86.	112.	147.	154.	130.	117.	138.	138.	111.	92.	107.	89.	1328.
MAI	.13	.02	.00	.02	.18	.26	.14	.14	.21	.29	.04	.08	.19

PROVIDENCIA LA YRS 15 ALT 785 METERS LAT 16 32 LON 93 59

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	SUM OR AV.
MEAN TEMP	20.9	21.5	22.5	24.1	24.9	23.9	24.2	24.3	24.0	22.8	21.4	21.2	23.0
MEAN RS	390.	450.	500.	450.	450.	390.	450.	400.	380.	350.	400.	350.	413.
PRECIP	0.	5.	4.	9.	112.	289.	199.	188.	271.	132.	11.	2.	1222.
PREC DEP	0.	0.	0.	0.	68.	192.	129.	121.	180.	82.	0.	0.	980.
POT ET	108.	114.	145.	131.	138.	113.	136.	121.	110.	102.	109.	98.	1425.
PREC DEF	108.	114.	145.	131.	70.	-79.	7.	-0.	-69.	20.	109.	98.	445.
MAI	.00	.00	.00	.00	.50	1.70	.95	1.00	1.63	.81	.00	.00	.69

PUEBLA YRS 15 ALT 2150 METERS LAT 19 2 LON 98 11

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	SUM OR AV.
MEAN TEMP	12.8	14.5	16.8	18.3	18.9	17.9	17.2	17.4	16.8	16.0	14.7	13.6	16.2
MEAN RS	400.	450.	500.	500.	470.	450.	440.	450.	440.	390.	370.	350.	435.
PRECIP	6.	6.	12.	13.	72.	157.	137.	171.	187.	57.	21.	9.	799.
PREC DEP	0.	0.	0.	0.	41.	100.	86.	75.	121.	30.	5.	0.	599.
POT ET	87.	94.	123.	125.	129.	111.	110.	113.	105.	92.	83.	78.	1249.
PREC DEF	87.	94.	123.	125.	88.	11.	24.	38.	-16.	62.	78.	78.	650.
MAI	.00	.00	.00	.00	.32	.90	.78	.66	1.15	.33	.06	.00	.48

TABLE 3 CLIMATE AND MOISTURE AVAILABILITY INDICES FOR MEXICO

PUENTE DE IXTLA YRS 15 ALT 900 METERS LAT 18 37 LON 99 19

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	SUM OR AV.
MEAN TEMP	20.4	22.6	25.0	26.2	27.8	26.4	25.6	25.2	24.7	24.4	22.6	21.0	24.3
MEAN RS	400.	460.	510.	510.	500.	440.	450.	450.	440.	390.	390.	360.	442.
PRECIP	2.	2.	4.	8.	56.	193.	193.	203.	219.	43.	9.	6.	939.
PREC DEP	0.	0.	0.	0.	29.	125.	125.	132.	144.	20.	0.	0.	725.
POT ET	109.	120.	157.	156.	164.	135.	141.	139.	130.	118.	109.	100.	1581.
PREC DEF	109.	120.	157.	156.	135.	10.	16.	7.	-13.	98.	109.	100.	856.
MAT	.00	.00	.00	.00	.18	.92	.89	.95	1.10	.17	.00	.00	.46

PUERTO MEXICO YRS 15 ALT 14 METERS LAT 18 9 LON 94 24

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	SUM OR AV.
MEAN TEMP	21.8	22.6	23.9	25.9	27.3	27.0	26.9	26.8	26.5	25.8	23.7	22.4	25.0
MEAN RS	350.	400.	460.	450.	490.	440.	430.	450.	400.	400.	350.	370.	409.
PRECIP	131.	65.	65.	36.	96.	263.	217.	376.	490.	559.	368.	218.	2884.
PREC DEP	82.	35.	36.	15.	57.	174.	142.	253.	333.	382.	247.	142.	2476.
POT ET	99.	105.	139.	137.	146.	137.	138.	144.	123.	125.	101.	95.	1490.
PREC DEF	18.	70.	102.	122.	89.	-37.	-4.	-109.	-210.	-257.	-146.	-47.	-986.
MAT	.82	.34	.26	.11	.39	1.27	1.03	1.76	2.70	3.06	2.45	1.50	1.66

PUNTA JEREZ YRS 15 ALT 0 METERS LAT 22 58 LON 97 46

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	SUM OR AV.
MEAN TEMP	17.4	19.1	20.7	23.8	26.0	26.6	27.2	27.3	26.8	25.1	21.3	17.8	23.3
MEAN RS	340.	400.	450.	550.	530.	520.	500.	500.	460.	400.	340.	320.	442.
PRECIP	47.	13.	4.	11.	53.	183.	199.	159.	306.	166.	42.	38.	1221.
PREC DEP	23.	0.	0.	0.	27.	118.	129.	101.	204.	106.	20.	16.	979.
POT ET	85.	95.	124.	159.	167.	161.	162.	163.	143.	123.	92.	81.	1556.
PREC DEF	62.	95.	124.	159.	140.	43.	33.	61.	-61.	17.	73.	65.	578.
MAT	.27	.00	.00	.00	.16	.74	.79	.62	1.43	.86	.21	.20	.63

QUERETARO YRS 15 ALT 1842 METERS LAT 20 36 LON 100 23

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	SUM OR AV.
MEAN TEMP	13.9	15.3	17.8	19.9	21.2	20.3	19.4	19.4	18.9	17.5	15.9	14.7	17.8
MEAN RS	390.	460.	510.	510.	500.	470.	440.	460.	440.	390.	390.	360.	443.
PRECIP	10.	4.	4.	11.	27.	93.	109.	87.	122.	34.	10.	12.	518.
PREC DEP	0.	0.	0.	0.	9.	55.	63.	51.	75.	13.	0.	0.	346.
POT ET	88.	98.	130.	133.	140.	124.	117.	122.	112.	98.	91.	83.	1336.
PREC DEF	88.	98.	130.	133.	131.	69.	54.	71.	37.	85.	91.	83.	990.
MAT	.00	.00	.00	.00	.07	.44	.54	.42	.67	.14	.00	.00	.26

QUIRIEGO YRS 15 ALT 0 METERS LAT 27 31 LON 109 15

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	SUM OR AV.
MEAN TEMP	17.0	18.7	20.6	24.3	26.6	31.0	31.4	31.4	30.4	27.8	22.4	18.0	25.0
MEAN RS	360.	420.	530.	600.	650.	660.	620.	590.	560.	530.	390.	370.	519.
PRECIP	20.	24.	5.	1.	7.	10.	214.	180.	94.	45.	17.	46.	663.
PREC DEP	4.	7.	0.	0.	0.	0.	140.	116.	56.	22.	2.	23.	477.
POT ET	89.	99.	146.	176.	208.	226.	221.	210.	189.	174.	109.	82.	1927.
PREC DEF	86.	92.	146.	176.	208.	226.	81.	94.	133.	153.	107.	59.	1451.
MAT	.04	.07	.00	.00	.00	.00	.63	.55	.30	.12	.01	.28	.25

RINCON DE ROMOS YRS 15 ALT 1950 METERS LAT 22 14 LON 102 19

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	SUM OR AV.
MEAN TEMP	11.7	13.6	15.4	17.5	19.9	20.9	19.2	19.2	19.1	17.8	14.9	12.3	16.8
MEAN RS	400.	460.	500.	530.	520.	430.	450.	400.	450.	400.	390.	360.	452.
PRECIP	17.	3.	5.	2.	36.	64.	138.	70.	88.	24.	21.	7.	473.
PREC DEP	2.	0.	0.	0.	15.	35.	87.	39.	52.	7.	4.	0.	306.
POT ET	84.	93.	118.	129.	140.	131.	119.	127.	115.	102.	88.	77.	1323.
PREC DEF	82.	93.	118.	129.	125.	97.	33.	88.	63.	95.	83.	77.	1017.
MAT	.02	.00	.00	.00	.11	.26	.73	.30	.45	.07	.05	.00	.23

TABLE 3 CLIMATE AND MOISTURE AVAILABILITY INDICES FOR MEXICO

RIO MANTE YRS 15 ALT 79 METERS LAT 22 42 LON 99 2

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	SUM OR AV.
MEAN TEMP	18.8	20.2	22.9	26.7	28.3	28.5	27.4	27.7	27.0	24.7	20.6	19.2	24.3
MEAN RS	350.	430.	470.	540.	520.	500.	450.	500.	460.	400.	360.	350.	445.
PRECIP	42.	15.	12.	18.	119.	165.	231.	198.	251.	109.	28.	9.	1197.
PREC DEP	20.	0.	0.	2.	73.	106.	152.	128.	166.	65.	10.	0.	953.
POT ET	92.	106.	137.	168.	173.	162.	150.	164.	144.	122.	96.	93.	1604.
PREC DEF	72.	106.	137.	165.	100.	56.	-2.	36.	-22.	57.	86.	93.	652.
MAI	.21	.00	.00	.01	.42	.65	1.01	.78	1.15	.53	.10	.00	.59

RIOVERDE YRS 15 ALT 986 METERS LAT 21 56 LON 99 59

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	SUM OR AV.
MEAN TEMP	15.6	17.7	19.8	23.1	24.6	24.2	23.3	23.3	22.6	20.5	17.8	15.9	20.7
MEAN RS	350.	450.	500.	520.	510.	490.	450.	490.	460.	390.	360.	350.	443.
PRECIP	18.	7.	6.	9.	54.	89.	83.	73.	121.	48.	70.	11.	537.
PREC DEP	2.	0.	0.	0.	28.	53.	48.	41.	74.	24.	4.	0.	364.
POT ET	83.	103.	134.	148.	155.	143.	133.	144.	129.	107.	88.	84.	1453.
PREC DEF	81.	103.	134.	148.	128.	91.	85.	103.	55.	83.	85.	84.	1089.
MAI	.03	.00	.00	.00	.18	.37	.36	.28	.58	.22	.04	.00	.25

RODEO EL YRS 15 ALT 1910 METERS LAT 25 11 LON 104 35

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	SUM OR AV.
MEAN TEMP	13.3	15.2	17.6	20.9	24.2	26.2	24.7	24.4	23.6	21.1	16.4	13.6	20.1
MEAN RS	350.	460.	520.	550.	550.	600.	530.	540.	500.	430.	390.	350.	481.
PRECIP	13.	7.	1.	7.	11.	48.	119.	76.	83.	30.	3.	9.	407.
PREC DEP	0.	0.	0.	0.	0.	23.	73.	43.	48.	11.	0.	0.	246.
POT ET	77.	98.	131.	147.	166.	184.	162.	164.	144.	120.	92.	78.	1564.
PREC DEF	77.	98.	131.	147.	166.	161.	89.	121.	96.	109.	92.	78.	1319.
MAI	.00	.00	.00	.00	.00	.13	.45	.26	.33	.09	.00	.00	.16

RIO GRANDE YRS 15 ALT 0 METERS LAT 23 50 LON 103 1

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	SUM OR AV.
MEAN TEMP	11.3	13.4	15.1	17.9	21.6	23.3	22.5	21.6	21.1	17.9	14.2	12.3	17.7
MEAN RS	360.	460.	520.	550.	540.	550.	490.	490.	470.	410.	400.	360.	467.
PRECIP	10.	9.	6.	4.	17.	57.	95.	63.	111.	71.	22.	13.	479.
PREC DEP	0.	0.	0.	0.	2.	30.	57.	34.	68.	12.	5.	0.	275.
POT ET	74.	92.	122.	135.	152.	157.	142.	138.	127.	104.	88.	77.	1409.
PREC DEF	74.	92.	122.	135.	151.	127.	85.	104.	59.	93.	83.	77.	1134.
MAI	.00	.00	.00	.00	.01	.19	.40	.25	.53	.11	.06	.00	.20

ROSARIO YRS 15 ALT 279 METERS LAT 27 53 LON 109 18

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	SUM OR AV.
MEAN TEMP	14.6	15.9	17.5	21.1	23.9	29.1	28.0	28.2	27.9	24.7	19.7	15.6	22.1
MEAN RS	360.	410.	530.	600.	650.	660.	620.	590.	560.	530.	390.	320.	518.
PRECIP	20.	26.	9.	3.	21.	45.	287.	174.	105.	44.	26.	60.	819.
PREC DEP	4.	8.	0.	0.	5.	21.	191.	112.	64.	21.	8.	32.	617.
POT ET	83.	89.	134.	162.	195.	216.	205.	196.	179.	162.	100.	76.	1796.
PREC DEF	79.	81.	134.	162.	190.	195.	14.	84.	115.	141.	91.	44.	1179.
MAI	.04	.09	.00	.00	.03	.10	.93	.57	.36	.13	.08	.42	.34

SABINAS YRS 15 ALT 339 METERS LAT 27 55 LON 101 18

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	SUM OR AV.
MEAN TEMP	9.3	14.4	16.7	22.0	28.0	33.6	32.6	32.5	28.1	21.4	16.0	10.6	22.1
MEAN RS	300.	380.	460.	550.	560.	620.	620.	560.	500.	420.	300.	280.	462.
PRECIP	23.	56.	46.	42.	89.	63.	37.	28.	134.	22.	25.	27.	593.
PREC DEP	6.	29.	22.	20.	52.	34.	16.	10.	84.	5.	7.	9.	413.
POT ET	59.	79.	113.	156.	185.	219.	227.	204.	160.	118.	70.	56.	1646.
PREC DEF	52.	49.	91.	136.	133.	185.	211.	194.	76.	113.	62.	48.	1232.
MAI	.11	.37	.20	.13	.28	.16	.07	.05	.52	.04	.11	.16	.25

TABLE 3 CLIMATE AND MOISTURE AVAILABILITY INDICES FOR MEXICO

SALINA CRUZ YRS 15 ALT 56 METERS LAT 16 12 LON 95 12

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	SUM OR AV.
MEAN TEMP	24.8	25.2	26.0	27.4	28.3	27.1	27.7	27.6	25.7	26.7	26.0	25.4	26.6
MEAN RS	350.	460.	500.	450.	500.	400.	450.	400.	400.	390.	400.	350.	421.
PRECIP	3.	1.	0.	5.	147.	334.	137.	161.	224.	99.	5.	1.	1116.
PREC DEP	0.	0.	0.	0.	93.	224.	86.	102.	146.	59.	0.	0.	804.
POT ET	107.	128.	159.	142.	166.	125.	148.	131.	124.	125.	122.	109.	1585.
PREC DEF	107.	128.	159.	142.	73.	-99.	62.	29.	-22.	66.	122.	109.	701.
MAI	.00	.00	.00	.00	.56	1.79	.58	.78	1.18	.47	.00	.00	.56

SALTO EL YRS 15 ALT 2538 METERS LAT 23 46 LON 105 22

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	SUM OR AV.
MEAN TEMP	6.3	6.5	8.0	10.6	12.9	22.2	15.4	15.5	15.2	12.8	9.3	7.2	11.8
MEAN RS	390.	450.	520.	540.	540.	550.	490.	490.	450.	430.	400.	350.	467.
PRECIP	37.	34.	8.	2.	36.	153.	193.	189.	129.	61.	23.	60.	925.
PREC DEP	16.	14.	0.	0.	15.	97.	125.	122.	80.	33.	6.	32.	713.
POT ET	66.	70.	95.	105.	118.	153.	116.	116.	102.	94.	74.	62.	1171.
PREC DEF	51.	56.	95.	105.	102.	55.	-9.	-6.	22.	61.	68.	30.	458.
MAI	.24	.20	.00	.00	.13	.64	1.08	1.05	.78	.35	.08	.52	.61

SALVATIERRA YRS 15 ALT 1760 METERS LAT 20 13 LON 100 53

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	SUM OR AV.
MEAN TEMP	16.7	17.5	19.6	21.6	23.4	22.9	21.8	21.3	21.0	20.0	17.9	16.5	20.0
MEAN RS	390.	470.	510.	520.	500.	530.	440.	460.	440.	390.	390.	360.	450.
PRECIP	10.	4.	7.	8.	37.	117.	182.	166.	165.	44.	10.	16.	766.
PREC DEP	0.	0.	0.	0.	16.	72.	117.	106.	105.	21.	0.	1.	569.
POT ET	95.	107.	136.	142.	148.	150.	125.	129.	118.	106.	96.	98.	1432.
PREC DEF	95.	107.	136.	142.	132.	78.	8.	22.	13.	85.	96.	97.	870.
MAI	.00	.00	.00	.00	.11	.48	.94	.83	.89	.20	.00	.01	.40

SAN ANDRES TUXTLA YRS 15 ALT 360 METERS LAT 18 26 LON 95 12

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	SUM OR AV.
MEAN TEMP	20.5	22.3	24.0	26.8	28.1	27.0	25.9	25.6	25.5	24.2	22.1	20.9	24.4
MEAN RS	340.	370.	440.	450.	480.	430.	440.	450.	400.	400.	350.	330.	403.
PRECIP	30.	17.	48.	13.	54.	222.	282.	313.	450.	441.	179.	63.	2114.
PREC DEP	11.	2.	24.	0.	28.	146.	187.	209.	305.	299.	116.	34.	1783.
POT ET	93.	86.	132.	140.	159.	134.	138.	141.	121.	121.	97.	91.	1453.
PREC DEF	82.	84.	108.	140.	131.	-11.	-49.	-69.	-185.	-178.	-19.	57.	-330.
MAI	.12	.02	.18	.00	.18	1.08	1.36	1.49	2.53	2.47	1.19	.38	1.23

SAN BLAS YRS 15 ALT 7 METERS LAT 21 32 LON 105 19

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	SUM OR AV.
MEAN TEMP	20.3	20.2	20.1	21.7	24.0	26.5	27.3	27.5	27.3	26.7	23.8	21.8	24.0
MEAN RS	390.	450.	500.	430.	530.	490.	500.	480.	450.	440.	400.	340.	450.
PRECIP	14.	5.	0.	0.	1.	211.	404.	329.	377.	111.	24.	28.	1464.
PREC DEP	0.	0.	0.	0.	0.	138.	273.	221.	226.	68.	7.	10.	1198.
POT ET	108.	111.	136.	118.	159.	151.	163.	157.	142.	141.	116.	97.	1597.
PREC DEF	109.	111.	136.	118.	159.	14.	-110.	-64.	-84.	73.	109.	87.	399.
MAI	.00	.00	.00	.00	.00	.91	1.68	1.41	1.60	.48	.06	.10	.75

SAN BUENAVENTURA YRS 15 ALT 1535 METERS LAT 29 50 LON 107 30

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	SUM OR AV.
MEAN TEMP	8.8	10.6	12.7	17.0	20.7	25.4	25.3	23.7	22.7	19.1	12.6	9.9	17.3
MEAN RS	330.	430.	540.	580.	660.	640.	650.	600.	560.	480.	370.	320.	513.
PRECIP	8.	17.	3.	11.	9.	26.	88.	108.	46.	29.	9.	21.	376.
PREC DEP	0.	2.	0.	0.	0.	8.	52.	65.	22.	10.	0.	5.	219.
POT ET	62.	78.	117.	139.	180.	193.	202.	179.	158.	127.	77.	60.	1572.
PREC DEF	62.	77.	117.	139.	180.	185.	150.	114.	136.	116.	77.	55.	1353.
MAI	.00	.02	.00	.00	.00	.04	.26	.37	.14	.08	.00	.08	.14

TABLE 3 CLIMATE AND MOISTURE AVAILABILITY INDICES FOR MEXICO

SAN CARLOS YAUTEPEC YRS 15 ALT 1000 METERS LAT 16 30 LON 96 6

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	SUM OR AV.
MEAN TEMP	19.6	21.5	22.8	24.0	25.4	24.7	24.0	24.2	23.5	23.3	22.1	21.2	23.0
MEAN RS	380.	470.	520.	450.	450.	390.	460.	420.	410.	400.	400.	350.	426.
PRECIP	0.	0.	4.	10.	57.	242.	87.	126.	166.	87.	11.	0.	790.
PREC DEP	0.	0.	0.	0.	30.	159.	51.	79.	106.	51.	0.	0.	591.
POT ET	102.	119.	151.	131.	140.	115.	139.	127.	118.	118.	111.	101.	1471.
PREC DEF	102.	119.	151.	131.	110.	-44.	88.	49.	12.	67.	111.	101.	880.
MAI	.00	.00	.00	.00	.21	1.38	.37	.62	.90	.43	.00	.00	.40

SAN CIRO YRS 15 ALT 882 METERS LAT 21 38 LON 99 50

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	SUM OR AV.
MEAN TEMP	15.2	18.7	21.1	23.7	25.8	25.5	23.5	24.3	24.3	21.1	17.6	15.5	21.4
MEAN RS	360.	450.	510.	510.	500.	490.	450.	490.	450.	390.	360.	350.	442.
PRECIP	28.	13.	6.	9.	54.	92.	170.	53.	172.	119.	74.	5.	795.
PREC DEP	9.	0.	0.	0.	28.	55.	109.	27.	110.	73.	13.	0.	558.
POT ET	85.	106.	142.	147.	157.	148.	134.	148.	132.	109.	88.	83.	1479.
PREC DEF	75.	106.	142.	147.	129.	93.	25.	121.	22.	35.	75.	83.	921.
MAI	.11	.00	.00	.00	.18	.37	.81	.18	.84	.67	.15	.00	.38

SAN CRISTOBAL YRS 15 ALT 2128 METERS LAT 16 44 LON 92 38

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	SUM OR AV.
MEAN TEMP	12.6	12.9	14.1	15.4	15.9	15.7	15.8	15.6	15.4	14.9	12.8	12.9	14.5
MEAN RS	350.	470.	500.	440.	450.	390.	410.	400.	350.	350.	410.	350.	406.
PRECIP	7.	2.	11.	35.	129.	249.	142.	159.	247.	152.	23.	15.	1171.
PREC DEP	0.	0.	0.	14.	81.	165.	89.	101.	163.	97.	6.	1.	934.
POT ET	76.	93.	113.	101.	108.	90.	98.	95.	80.	82.	86.	76.	1098.
PREC DEF	76.	93.	113.	87.	28.	-74.	9.	-6.	-83.	-15.	80.	76.	164.
MAI	.00	.00	.00	.14	.75	1.83	.91	1.06	2.03	1.19	.07	.01	.85

SAN DIEGO CURUCUPASEO YRS 15 ALT 1020 METERS LAT 19 18 LON 101 9

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	SUM OR AV.
MEAN TEMP	23.3	24.4	25.7	26.8	27.3	26.3	25.2	25.0	24.8	24.7	24.5	23.7	25.1
MEAN RS	400.	470.	510.	520.	500.	460.	450.	460.	450.	400.	400.	370.	449.
PRECIP	11.	4.	4.	4.	24.	178.	194.	176.	210.	69.	22.	12.	895.
PREC DEP	0.	0.	0.	0.	7.	114.	119.	113.	137.	37.	5.	0.	686.
POT ET	118.	129.	160.	162.	163.	141.	139.	141.	133.	122.	118.	110.	1636.
PREC DEF	118.	129.	160.	162.	155.	27.	20.	28.	-3.	85.	113.	110.	950.
MAI	.00	.00	.00	.00	.04	.81	.85	.80	1.03	.31	.04	.00	.42

SAN DIEGO UNION YRS 15 ALT 2079 METERS LAT 21 29 LON 100 52

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	SUM OR AV.
MEAN TEMP	12.6	14.2	16.4	18.3	21.4	20.6	18.9	19.2	18.5	16.9	14.1	13.1	17.0
MEAN RS	380.	470.	510.	530.	510.	490.	450.	470.	450.	390.	370.	360.	448.
PRECIP	21.	6.	13.	6.	44.	99.	111.	75.	120.	35.	5.	24.	558.
PREC DEP	5.	0.	0.	0.	21.	59.	68.	42.	74.	15.	0.	7.	382.
POT ET	82.	97.	124.	132.	143.	128.	118.	124.	113.	97.	81.	79.	1320.
PREC DEF	78.	97.	124.	132.	122.	69.	51.	82.	39.	82.	81.	73.	937.
MAI	.06	.00	.00	.00	.15	.46	.57	.34	.65	.15	.00	.08	.29

SAN IGNACIO YRS 15 ALT 150 METERS LAT 23 56 LON 106 26

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	SUM OR AV.
MEAN TEMP	19.5	20.4	21.8	24.2	26.9	29.0	28.3	28.3	27.5	27.2	23.8	21.3	24.8
MEAN RS	370.	450.	510.	540.	540.	570.	500.	490.	450.	430.	400.	340.	466.
PRECIP	14.	12.	6.	0.	9.	57.	226.	175.	173.	62.	9.	44.	789.
PREC DEP	0.	0.	0.	0.	0.	30.	148.	113.	111.	34.	0.	21.	590.
POT ET	99.	111.	145.	158.	174.	187.	166.	163.	142.	140.	116.	95.	1694.
PREC DEF	99.	111.	145.	158.	174.	157.	18.	50.	31.	106.	116.	74.	1104.
MAI	.00	.00	.00	.00	.00	.16	.89	.69	.78	.24	.00	.22	.35

TABLE 3 CLIMATE AND MOISTURE AVAILABILITY INDICES FOR MEXICO

SAN JUAN DE GUADALUPE YRS 15 ALT 1570 METERS LAT 24 37 LON 102 38

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	SUM OR AV.
MEAN TEMP	18.9	20.4	21.5	22.3	23.8	23.8	23.8	23.8	22.8	22.6	21.5	19.4	22.0
MEAN RS	350.	460.	520.	550.	550.	600.	520.	570.	490.	410.	350.	330.	471.
PRECIP	7.	9.	4.	3.	11.	53.	87.	58.	71.	34.	20.	14.	370.
PREC DEP	0.	0.	0.	0.	0.	27.	51.	30.	40.	14.	4.	0.	213.
POT ET	92.	114.	146.	153.	164.	174.	155.	158.	135.	119.	95.	88.	1594.
PREC DEF	92.	114.	146.	153.	164.	147.	105.	128.	95.	105.	91.	88.	1380.
MAI	.00	.00	.00	.00	.00	.15	.33	.19	.30	.11	.04	.00	.13

SAN JUAN IXCAQUISTLA YRS 15 ALT 1850 METERS LAT 18 28 LON 97 49

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	SUM OR AV.
MEAN TEMP	14.0	15.1	16.7	19.1	19.4	18.9	18.0	17.8	17.5	16.6	15.1	14.5	16.9
MEAN RS	350.	450.	500.	490.	490.	430.	440.	450.	420.	380.	350.	340.	424.
PRECIP	5.	6.	13.	12.	91.	173.	165.	121.	164.	76.	13.	1.	787.
PREC DEP	0.	0.	0.	0.	54.	111.	64.	75.	105.	44.	0.	0.	594.
POT ET	79.	98.	123.	122.	132.	109.	112.	114.	102.	93.	79.	78.	1244.
PREC DEF	79.	98.	123.	122.	79.	-2.	49.	39.	-3.	50.	79.	78.	660.
MAI	.00	.00	.00	.00	.41	1.02	.57	.66	1.03	.47	.00	.00	.47

SAN JUAN DEL RIO YRS 15 ALT 1700 METERS LAT 24 45 LON 104 26

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	SUM OR AV.
MEAN TEMP	12.8	14.3	16.1	19.1	20.9	23.1	21.4	20.1	20.0	18.4	15.7	12.5	17.9
MEAN RS	360.	460.	520.	540.	540.	550.	500.	500.	470.	430.	400.	350.	468.
PRECIP	8.	8.	1.	3.	26.	62.	144.	86.	75.	29.	7.	10.	459.
PREC DEP	0.	0.	0.	0.	8.	34.	90.	50.	42.	11.	0.	6.	293.
POT ET	78.	95.	126.	138.	150.	156.	140.	136.	123.	111.	92.	78.	1423.
PREC DEF	78.	95.	126.	138.	141.	122.	50.	85.	81.	101.	92.	78.	1170.
MAI	.00	.00	.00	.00	.05	.22	.64	.37	.34	.10	.00	.00	.21

SAN JUAN DEL RIO YRS 15 ALT 0 METERS LAT 20 23 LON 100 0

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	SUM OR AV.
MEAN TEMP	13.1	15.0	17.0	19.0	20.5	20.2	18.9	19.2	18.8	16.9	14.8	13.9	17.3
MEAN RS	390.	460.	510.	520.	500.	490.	440.	460.	440.	390.	390.	360.	445.
PRECIP	12.	8.	9.	15.	43.	115.	108.	82.	126.	44.	19.	7.	587.
PREC DEP	0.	0.	0.	1.	20.	70.	66.	47.	78.	21.	3.	0.	408.
POT ET	86.	97.	127.	132.	137.	126.	115.	122.	112.	97.	88.	81.	1320.
PREC DEF	86.	97.	127.	132.	117.	56.	49.	74.	34.	75.	85.	81.	911.
MAI	.00	.00	.00	.01	.14	.55	.57	.39	.70	.22	.03	.00	.31

SAN LUIS COLORADO YRS 15 ALT 39 METERS LAT 32 29 LON 114 50

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	SUM OR AV.
MEAN TEMP	11.9	14.7	18.3	21.5	25.4	29.7	34.4	34.0	30.2	23.5	16.8	12.4	22.7
MEAN RS	300.	390.	510.	590.	630.	710.	670.	620.	550.	420.	350.	300.	502.
PRECIP	7.	9.	4.	3.	1.	0.	9.	12.	6.	8.	3.	14.	76.
PREC DEP	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
POT ET	63.	80.	132.	161.	196.	236.	254.	233.	185.	125.	84.	64.	1811.
PREC DEF	63.	80.	132.	161.	196.	236.	254.	233.	185.	125.	84.	64.	1811.
MAI	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00

SAN LUIS DE PAZ YRS 15 ALT 1932 METERS LAT 21 36 LON 100 32

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	SUM OR AV.
MEAN TEMP	12.6	14.1	16.7	17.8	20.1	19.7	19.4	19.4	18.5	16.6	13.8	13.3	16.8
MEAN RS	380.	460.	510.	530.	500.	490.	450.	470.	450.	390.	370.	350.	447.
PRECIP	12.	6.	7.	2.	44.	65.	67.	35.	82.	22.	14.	16.	371.
PREC DEP	0.	0.	0.	0.	21.	36.	37.	14.	47.	5.	0.	1.	214.
POT ET	82.	98.	126.	130.	136.	127.	120.	125.	113.	96.	80.	80.	1309.
PREC DEF	82.	98.	126.	130.	115.	91.	83.	111.	66.	91.	80.	79.	1095.
MAI	.00	.00	.00	.00	.15	.28	.31	.11	.42	.05	.00	.02	.16

TABLE 1 CLIMATE AND MOISTURE AVAILABILITY INDICES FOR MEXICO

SAN LUIS POTOSI YRS 15 ALT 1877 METERS LAT 22 9 LON 100 58

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	SUM OR AV.
MEAN TEMP	12.9	15.0	17.0	20.4	21.5	20.9	19.5	19.6	18.4	17.2	14.8	13.9	17.6
MEAN RS	370.	450.	500.	540.	510.	500.	450.	490.	460.	400.	360.	350.	448.
PRECIP	11.	5.	10.	5.	30.	72.	57.	43.	85.	18.	9.	14.	359.
PREC DEP	0.	0.	0.	0.	11.	40.	30.	20.	50.	2.	0.	0.	205.
POT ET	81.	95.	124.	143.	144.	134.	120.	131.	115.	100.	81.	79.	1346.
PREC DEF	81.	95.	124.	143.	133.	94.	90.	111.	66.	98.	81.	79.	1142.
MAI	.00	.00	.00	.00	.08	.30	.25	.15	.43	.02	.00	.00	.15

SAN MARCOS YRS 15 ALT 910 METERS LAT 16 42 LON 99 21

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	SUM OR AV.
MEAN TEMP	13.3	15.6	18.0	20.4	22.3	21.0	19.8	19.1	19.1	17.6	15.2	14.0	17.9
MEAN RS	410.	480.	520.	500.	510.	450.	500.	500.	450.	450.	410.	390.	464.
PRECIP	0.	0.	0.	0.	11.	209.	190.	180.	390.	94.	4.	0.	1077.
PREC DEP	0.	0.	0.	0.	0.	136.	116.	116.	268.	56.	0.	0.	850.
POT ET	91.	103.	133.	132.	147.	121.	134.	132.	115.	114.	93.	88.	1403.
PREC DEF	91.	103.	133.	132.	147.	-15.	18.	16.	-154.	58.	93.	88.	553.
MAI	.00	.00	.00	.00	.00	1.13	.87	.88	2.34	.49	.00	.00	.61

SAN MIGUEL ALLENDE YRS 15 ALT 1852 METERS LAT 20 57 LON 100 45

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	SUM OR AV.
MEAN TEMP	13.3	15.6	18.0	20.4	22.3	21.0	19.8	19.1	19.1	17.6	15.2	14.0	17.9
MEAN RS	400.	470.	510.	520.	500.	490.	440.	460.	440.	390.	390.	360.	447.
PRECIP	9.	7.	7.	9.	28.	115.	104.	94.	110.	25.	14.	17.	539.
PREC DEP	0.	0.	0.	0.	10.	71.	63.	56.	67.	8.	0.	2.	365.
POT ET	88.	101.	130.	138.	144.	129.	118.	121.	112.	99.	89.	91.	1351.
PREC DEF	88.	101.	130.	138.	134.	58.	55.	65.	46.	91.	89.	90.	986.
MAI	.00	.00	.00	.00	.07	.55	.53	.46	.59	.08	.00	.02	.27

SAN RAFAEL YRS 15 ALT 2529 METERS LAT 19 13 LON 98 49

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	SUM OR AV.
MEAN TEMP	11.1	12.0	13.5	14.8	15.1	14.5	13.4	13.6	13.5	13.2	12.2	11.8	13.2
MEAN RS	400.	460.	500.	500.	490.	450.	440.	450.	440.	390.	370.	350.	437.
PRECIP	11.	9.	13.	41.	86.	179.	270.	225.	221.	72.	31.	21.	1179.
PREC DEP	0.	0.	0.	19.	50.	116.	179.	147.	145.	40.	12.	4.	941.
POT ET	82.	88.	111.	112.	115.	100.	97.	101.	95.	86.	76.	73.	1138.
PREC DEF	82.	88.	111.	93.	65.	-15.	-82.	-47.	-50.	46.	64.	69.	196.
MAI	.00	.00	.00	.17	.44	1.15	1.84	1.47	1.52	.47	.16	.06	.83

SANTA ANA YRS 15 ALT 685 METERS LAT 30 34 LON 111 7

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	SUM OR AV.
MEAN TEMP	11.7	13.6	15.9	18.7	23.1	28.6	30.0	29.4	28.2	24.1	18.2	12.3	21.2
MEAN RS	310.	410.	540.	630.	680.	700.	660.	610.	560.	470.	400.	320.	524.
PRECIP	12.	22.	14.	6.	4.	20.	109.	87.	47.	21.	16.	27.	385.
PREC DEP	0.	5.	0.	0.	0.	4.	66.	51.	23.	5.	1.	9.	226.
POT ET	65.	83.	130.	159.	200.	227.	228.	208.	180.	142.	100.	68.	1788.
PREC DEF	65.	77.	130.	159.	200.	223.	162.	157.	157.	137.	99.	59.	1562.
MAI	.06	.07	.00	.00	.00	.02	.29	.24	.13	.03	.01	.13	.13

SANTIAGO DE LA PENINSULA YRS 15 ALT 10 METERS LAT 21 58 LON 97 29

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	SUM OR AV.
MEAN TEMP	18.8	20.4	22.1	25.4	27.6	29.0	27.6	27.7	26.6	25.3	21.7	19.3	24.3
MEAN RS	350.	410.	470.	550.	520.	500.	480.	480.	460.	400.	350.	320.	441.
PRECIP	47.	31.	24.	23.	101.	261.	185.	163.	314.	222.	65.	34.	1470.
PREC DEP	23.	17.	7.	6.	61.	130.	120.	104.	210.	145.	36.	13.	1149.
POT ET	92.	101.	135.	165.	170.	160.	157.	157.	142.	124.	96.	85.	1585.
PREC DEF	68.	90.	128.	159.	110.	29.	37.	53.	-67.	-21.	61.	71.	436.
MAI	.25	.17	.05	.04	.36	.82	.76	.66	1.47	1.17	.37	.16	.72

TABLE 3 CLIMATE AND MOISTURE AVAILABILITY INDICES FOR MEXICO

SANTIAGO PAPASQUIAR   YRS 15   ALT 1739 METERS   LAT 25 2   LON 105 26

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	SUM OR AV.
MEAN TEMP	10.6	12.9	15.2	18.2	21.0	23.3	21.9	21.4	20.7	18.2	14.3	11.4	17.4
MEAN RS	350.	450.	530.	550.	550.	600.	560.	530.	500.	440.	400.	350.	484.
PRECIP	12.	9.	7.	11.	15.	68.	130.	104.	78.	29.	10.	23.	457.
PREC DEP	0.	0.	0.	0.	0.	37.	85.	63.	44.	10.	0.	6.	327.
POT ET	70.	89.	125.	137.	153.	171.	159.	149.	133.	113.	88.	73.	1460.
PREC DEF	70.	89.	125.	137.	152.	134.	74.	86.	89.	103.	88.	66.	1134.
MAT	.00	.00	.00	.00	.00	.22	.53	.42	.33	.09	.00	.09	.22

SANTIAGO VALLE   YRS 15   ALT 1779 METERS   LAT 20 24   LON 101 25

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	SUM OR AV.
MEAN TEMP	16.4	18.4	20.8	22.7	23.9	23.2	21.2	21.6	21.2	20.4	18.5	16.5	20.4
MEAN RS	390.	470.	510.	530.	500.	490.	450.	560.	440.	390.	400.	370.	457.
PRECIP	4.	4.	8.	7.	22.	75.	171.	151.	141.	49.	37.	29.	649.
PREC DEP	0.	0.	0.	0.	6.	8.	110.	96.	89.	24.	16.	10.	464.
POT ET	95.	110.	141.	149.	150.	137.	126.	158.	119.	107.	100.	91.	1483.
PREC DEF	95.	110.	141.	149.	144.	129.	15.	62.	30.	83.	85.	81.	1018.
MAT	.00	.00	.00	.00	.04	.06	.87	.61	.75	.22	.16	.11	.31

SANTIAGUILLO   YRS 15   ALT 3 METERS   LAT 19 8   LON 95 49

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	SUM OR AV.
MEAN TEMP	24.2	23.9	24.4	26.4	27.8	28.9	28.2	28.2	28.7	27.9	26.2	24.6	26.6
MEAN RS	340.	400.	400.	490.	500.	450.	450.	460.	450.	400.	340.	330.	417.
PRECIP	24.	19.	14.	17.	42.	210.	247.	283.	346.	250.	96.	48.	1595.
PREC DEP	7.	3.	0.	2.	20.	137.	163.	188.	232.	165.	57.	24.	1316.
POT ET	103.	108.	121.	151.	164.	147.	149.	153.	146.	132.	104.	101.	1579.
PREC DEF	96.	105.	121.	149.	145.	10.	-14.	-36.	-86.	-33.	47.	77.	263.
MAT	.07	.03	.00	.01	.12	.93	1.09	1.23	1.59	1.25	.55	.24	.83

SANTO DOMINGO   YRS 15   ALT 89 METERS   LAT 16 32   LON 94 36

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	SUM OR AV.
MEAN TEMP	24.3	25.4	27.1	27.8	28.7	27.7	27.9	28.0	27.8	26.6	25.6	24.5	26.8
MEAN RS	350.	460.	500.	450.	450.	400.	440.	400.	390.	360.	350.	350.	408.
PRECIP	0.	1.	2.	5.	87.	357.	197.	182.	364.	170.	9.	2.	1376.
PREC DEP	0.	0.	0.	0.	51.	240.	128.	117.	245.	109.	0.	0.	1118.
POT ET	106.	129.	162.	143.	151.	127.	145.	132.	124.	115.	106.	106.	1547.
PREC DEF	106.	129.	162.	143.	100.	-113.	17.	15.	-121.	6.	106.	106.	428.
MAT	.00	.00	.00	.00	.34	1.89	.88	.89	1.97	.95	.00	.00	.72

SAN VICENTE JAUMAVE   YRS 15   ALT 735 METERS   LAT 23 25   LON 99 19

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	SUM OR AV.
MEAN TEMP	15.8	17.6	19.6	22.3	24.7	25.4	24.5	24.7	24.1	21.7	17.8	16.1	21.2
MEAN RS	300.	420.	460.	550.	540.	580.	540.	520.	470.	400.	350.	300.	452.
PRECIP	27.	13.	12.	31.	85.	227.	195.	141.	201.	88.	37.	19.	1076.
PREC DEP	9.	0.	0.	12.	49.	149.	126.	89.	131.	51.	16.	3.	849.
POT ET	72.	96.	123.	153.	165.	175.	164.	159.	137.	113.	86.	72.	1515.
PREC DEF	63.	96.	123.	141.	116.	26.	38.	70.	6.	62.	70.	69.	667.
MAT	.13	.00	.00	.08	.30	.85	.77	.56	.96	.45	.19	.04	.56

SIERRA MOJADA   YRS 15   ALT 1256 METERS   LAT 27 17   LON 103 42

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	SUM OR AV.
MEAN TEMP	13.2	15.7	18.6	22.6	26.0	28.3	27.2	26.7	24.5	21.8	17.3	12.9	21.2
MEAN RS	300.	450.	500.	590.	600.	630.	610.	560.	530.	440.	350.	300.	488.
PRECIP	17.	9.	9.	7.	23.	46.	80.	67.	84.	29.	9.	14.	394.
PREC DEP	2.	0.	0.	0.	6.	23.	46.	37.	48.	10.	0.	0.	234.
POT ET	66.	97.	130.	166.	189.	203.	199.	180.	156.	125.	85.	65.	1659.
PREC DEF	64.	97.	130.	166.	183.	180.	152.	143.	107.	115.	85.	65.	1425.
MAT	.03	.00	.00	.00	.03	.11	.23	.21	.31	.08	.00	.00	.14

TABLE 3 CLIMATE AND MOISTURE AVAILABILITY INDICES FOR MEXICO

SILAO YRS 15 ALT 1777 METERS LAT 20 56 LON 101 25

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	SUM OR AV.
MEAN TEMP	14.1	15.9	17.7	19.9	21.5	21.6	20.7	20.4	20.1	18.7	16.5	15.2	18.5
MEAN RS	400.	460.	510.	530.	500.	490.	450.	460.	440.	390.	400.	370.	449.
PRECIP	21.	10.	10.	6.	30.	151.	182.	166.	180.	47.	17.	21.	840.
PREC DEP	5.	0.	0.	0.	11.	95.	118.	106.	116.	23.	7.	5.	636.
POT ET	91.	100.	129.	138.	141.	131.	124.	126.	116.	102.	95.	87.	1379.
PREC DEF	86.	100.	129.	138.	130.	36.	6.	20.	-1.	79.	87.	82.	744.
MAT	.05	.00	.00	.00	.08	.73	.95	.84	1.01	.22	.02	.05	.46

SIMOJOVEL YRS 15 ALT 250 METERS LAT 17 9 LON 92 38

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	SUM OR AV.
MEAN TEMP	20.3	22.4	24.4	25.9	26.4	25.6	25.3	25.2	25.3	24.0	21.9	21.3	24.0
MEAN RS	340.	440.	450.	410.	460.	400.	400.	460.	350.	400.	390.	340.	403.
PRECIP	72.	30.	46.	42.	159.	220.	162.	220.	232.	198.	106.	94.	1572.
PREC DEP	40.	11.	22.	20.	101.	144.	103.	144.	152.	122.	64.	56.	1295.
POT ET	93.	115.	136.	125.	146.	121.	124.	142.	105.	120.	107.	95.	1430.
PREC DEF	53.	104.	114.	105.	45.	-23.	21.	-2.	-47.	-2.	43.	79.	135.
MAT	.43	.10	.16	.16	.69	1.19	.83	1.01	1.45	1.01	.60	.59	.91

SOLEDAD DOBLADO YRS 15 ALT 182 METERS LAT 19 4 LON 96 24

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	SUM OR AV.
MEAN TEMP	22.2	23.5	25.7	28.6	30.0	29.5	28.4	27.3	27.4	26.8	24.3	21.7	26.3
MEAN RS	340.	400.	410.	490.	500.	450.	450.	460.	390.	400.	340.	330.	413.
PRECIP	8.	2.	0.	3.	19.	119.	182.	186.	164.	125.	26.	11.	844.
PREC DEP	0.	0.	0.	0.	4.	73.	117.	120.	105.	77.	8.	0.	639.
POT ET	98.	107.	128.	159.	173.	149.	150.	150.	123.	128.	100.	94.	1557.
PREC DEF	98.	107.	128.	159.	169.	75.	33.	29.	18.	51.	92.	94.	918.
MAT	.00	.00	.00	.00	.02	.49	.78	.80	.85	.60	.08	.00	.41

SOMBRERETE YRS 15 ALT 2350 METERS LAT 23 19 LON 103 37

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	SUM OR AV.
MEAN TEMP	10.0	1.2	14.0	17.3	19.4	21.0	18.9	18.9	17.8	16.1	13.0	11.4	14.9
MEAN RS	360.	470.	520.	530.	530.	560.	430.	480.	450.	420.	400.	360.	460.
PRECIP	16.	10.	1.	5.	23.	74.	150.	96.	111.	47.	21.	29.	582.
PREC DEP	1.	0.	0.	0.	6.	42.	102.	50.	68.	23.	4.	11.	404.
POT ET	71.	57.	119.	128.	141.	151.	113.	126.	113.	101.	85.	75.	1277.
PREC DEF	70.	57.	119.	128.	135.	109.	11.	76.	46.	79.	80.	64.	974.
MAT	.02	.00	.00	.00	.04	.28	.91	.40	.60	.22	.05	.14	.32

SOTO LA MARINA YRS 15 ALT 25 METERS LAT 23 46 LON 98 12

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	SUM OR AV.
MEAN TEMP	16.9	19.5	21.0	24.4	26.9	27.9	27.2	28.1	26.9	24.4	20.5	17.1	23.3
MEAN RS	340.	410.	450.	520.	540.	550.	510.	520.	470.	410.	340.	300.	447.
PRECIP	62.	13.	2.	23.	118.	175.	139.	138.	271.	91.	117.	14.	1108.
PREC DEP	34.	0.	0.	6.	73.	113.	87.	86.	145.	53.	68.	0.	977.
POT ET	84.	96.	125.	153.	174.	175.	166.	172.	146.	124.	90.	75.	1580.
PREC DEF	50.	96.	125.	146.	101.	63.	78.	86.	2.	71.	22.	75.	704.
MAT	.40	.00	.00	.04	.42	.64	.57	.50	.99	.43	.75	.00	.55

TAMAZULA GORDIANO YRS 15 ALT 1285 METERS LAT 19 39 LON 103 10

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	SUM OR AV.
MEAN TEMP	19.0	20.0	21.5	23.4	24.9	25.3	24.0	24.0	24.0	23.5	21.5	19.9	22.6
MEAN RS	400.	460.	500.	530.	510.	470.	490.	490.	450.	420.	410.	370.	457.
PRECIP	12.	3.	0.	1.	25.	200.	172.	191.	171.	125.	42.	34.	977.
PREC DEP	0.	0.	0.	0.	7.	130.	111.	124.	110.	77.	20.	14.	759.
POT ET	105.	112.	141.	152.	156.	141.	147.	144.	131.	125.	112.	100.	1566.
PREC DEF	105.	112.	141.	152.	149.	11.	36.	20.	21.	47.	92.	86.	807.
MAT	.00	.00	.00	.00	.05	.92	.75	.86	.84	.62	.17	.14	.48

TABLE 3 CLIMATE AND MOISTURE AVAILABILITY INDICES FOR MEXICO

TAMPICO YRS 15 ALT 17 METERS LAT 22 12 LON 97 51

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	SUM OR AV.
MEAN TEMP	18.8	20.3	22.0	24.8	26.9	27.9	28.1	28.3	27.3	25.6	22.3	19.3	24.3
MEAN RS	350.	430.	450.	550.	520.	540.	500.	500.	460.	400.	350.	310.	447.
PRECIP	52.	23.	12.	10.	50.	199.	148.	151.	332.	177.	56.	42.	1252.
PREC DEP	27.	6.	0.	0.	25.	130.	93.	95.	222.	114.	29.	20.	1007.
POT ET	92.	106.	129.	163.	167.	172.	166.	156.	145.	125.	97.	82.	1609.
PREC DEF	65.	100.	128.	163.	143.	43.	72.	71.	-78.	11.	68.	63.	603.
MAI	.29	.06	.00	.00	.15	.75	.55	.57	1.54	.91	.30	.24	.63

TANTOYUCA YRS 15 ALT 217 METERS LAT 21 21 LON 98 13

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	SUM OR AV.
MEAN TEMP	17.9	18.8	22.7	25.4	26.0	26.4	25.5	26.3	25.8	23.9	20.1	16.8	23.0
MEAN RS	350.	410.	490.	540.	510.	500.	480.	490.	460.	390.	360.	340.	443.
PRECIP	25.	56.	18.	38.	86.	202.	159.	154.	211.	114.	59.	52.	1172.
PREC DEP	7.	29.	2.	16.	50.	171.	101.	98.	138.	70.	31.	26.	739.
POT ET	99.	97.	142.	162.	161.	154.	150.	155.	140.	117.	95.	94.	1546.
PREC DEF	82.	68.	140.	146.	111.	73.	48.	58.	2.	47.	63.	58.	611.
MAI	.08	.30	.02	.10	.31	.85	.68	.63	.99	.60	.33	.31	.60

TAPACHULA YRS 15 ALT 167 METERS LAT 14 54 LON 92 16

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	SUM OR AV.
MEAN TEMP	25.2	25.6	26.4	27.2	26.6	25.3	25.8	25.6	25.2	25.1	25.2	25.2	25.7
MEAN RS	360.	470.	510.	480.	470.	370.	460.	400.	400.	400.	470.	490.	439.
PRECIP	7.	6.	32.	73.	312.	473.	298.	331.	453.	405.	89.	11.	2490.
PREC DEP	0.	0.	12.	41.	209.	321.	199.	221.	307.	274.	51.	0.	2121.
POT ET	111.	133.	162.	151.	150.	111.	144.	125.	120.	123.	141.	148.	1620.
PREC DEF	111.	133.	150.	109.	-58.	-210.	-54.	-96.	-187.	-150.	89.	148.	-501.
MAI	.00	.00	.08	.27	1.39	2.89	1.38	1.77	2.57	2.22	.37	.00	1.31

TAPALPA YRS 15 ALT 1564 METERS LAT 20 0 LON 103 45

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	SUM OR AV.
MEAN TEMP	13.0	14.0	16.3	18.1	19.8	19.7	19.3	18.7	19.1	17.6	15.8	14.5	17.1
MEAN RS	400.	460.	510.	530.	520.	480.	500.	490.	450.	420.	400.	370.	461.
PRECIP	25.	9.	6.	6.	56.	179.	111.	119.	128.	107.	29.	53.	777.
PREC DEP	8.	0.	0.	0.	29.	80.	68.	73.	79.	65.	10.	27.	580.
POT ET	88.	94.	124.	132.	140.	124.	133.	128.	112.	106.	93.	85.	1359.
PREC DEF	80.	94.	124.	132.	111.	44.	65.	55.	33.	41.	82.	58.	778.
MAI	.09	.00	.00	.00	.21	.64	.51	.57	.71	.61	.11	.32	.43

TAXCO YRS 15 ALT 1754 METERS LAT 18 33 LON 99 36

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	SUM OR AV.
MEAN TEMP	19.2	20.7	22.1	23.9	24.7	22.3	21.1	20.8	20.7	20.7	19.8	19.6	21.3
MEAN RS	390.	470.	520.	510.	500.	430.	450.	450.	440.	390.	390.	360.	442.
PRECIP	1.	5.	9.	23.	77.	269.	301.	342.	329.	90.	5.	3.	1455.
PREC DEP	0.	0.	0.	6.	44.	179.	201.	229.	221.	53.	0.	0.	1189.
POT ET	103.	117.	149.	148.	153.	120.	125.	124.	117.	108.	101.	96.	1462.
PREC DEF	103.	117.	149.	142.	109.	-59.	-76.	-105.	-103.	55.	101.	96.	273.
MAI	.00	.00	.00	.04	.29	1.49	1.60	1.84	1.88	.49	.00	.00	.81

TEAPA YRS 15 ALT 79 METERS LAT 17 33 LON 92 57

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	SUM OR AV.
MEAN TEMP	21.8	22.8	24.1	26.3	27.6	27.1	26.8	26.9	26.3	25.2	23.2	22.5	25.0
MEAN RS	330.	450.	500.	400.	450.	400.	400.	460.	350.	400.	390.	340.	406.
PRECIP	366.	249.	207.	114.	190.	377.	344.	375.	572.	508.	309.	345.	3967.
PREC DEP	246.	165.	135.	69.	129.	254.	231.	252.	390.	346.	206.	232.	3447.
POT ET	94.	118.	151.	123.	147.	125.	128.	148.	107.	124.	111.	98.	1475.
PREC DEF	-152.	-46.	16.	53.	19.	-129.	-102.	-104.	-283.	-222.	-95.	-134.	-1972.
MAI	2.63	1.39	.90	.57	.87	2.03	1.80	1.71	3.63	2.79	1.65	2.36	2.38

TABLE 3 CLIMATE AND MOISTURE AVAILABILITY INDICES FOR MEXICO

TECOLUTLA YRS 10 ALT 3 METERS LAT 20 30 LON 97 1

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	SUM OR AV.
MEAN TEMP	19.4	21.2	21.0	22.8	25.1	25.3	25.7	25.6	24.7	24.0	22.1	19.2	23.0
MEAN RS	350.	400.	480.	500.	500.	470.	450.	470.	450.	390.	350.	290.	429.
PRECIP	62.	51.	68.	14.	48.	200.	142.	173.	281.	284.	85.	74.	1431.
PREC DEP	33.	25.	37.	0.	24.	130.	89.	76.	187.	199.	49.	42.	1168.
POT ET	93.	101.	133.	141.	154.	141.	139.	147.	133.	117.	97.	90.	1487.
PREC DEF	60.	75.	96.	141.	131.	11.	50.	71.	-54.	-71.	48.	48.	319.
MAI	.36	.25	.28	.00	.15	.92	.64	.52	1.40	1.61	.51	.46	.79

TEHUACAN YRS 15 ALT 1675 METERS LAT 18 28 LON 97 23

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	SUM OR AV.
MEAN TEMP	15.8	16.8	18.5	20.0	21.2	20.8	19.5	19.9	20.1	18.2	16.7	16.1	18.6
MEAN RS	360.	450.	500.	450.	490.	430.	430.	450.	410.	390.	360.	340.	421.
PRECIP	2.	3.	4.	17.	67.	95.	71.	57.	195.	32.	4.	6.	553.
PREC DEP	0.	0.	0.	2.	37.	56.	40.	30.	127.	12.	0.	0.	378.
POT ET	86.	100.	130.	118.	137.	115.	115.	121.	108.	98.	86.	82.	1296.
PREC DEF	86.	100.	130.	116.	100.	58.	75.	91.	-19.	86.	86.	82.	918.
MAI	.00	.00	.00	.01	.27	.49	.35	.25	1.17	.12	.00	.00	.29

TEMOSACHIC YRS 15 ALT 1957 METERS LAT 28 58 LON 107 50

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	SUM OR AV.
MEAN TEMP	4.3	6.6	8.7	11.7	16.6	21.0	21.8	21.2	18.7	14.0	8.2	4.8	13.1
MEAN RS	350.	430.	530.	600.	630.	640.	600.	560.	550.	470.	400.	330.	507.
PRECIP	9.	4.	7.	7.	12.	27.	109.	129.	65.	30.	15.	40.	454.
PREC DEP	0.	0.	0.	0.	0.	9.	66.	80.	35.	11.	0.	19.	299.
POT ET	54.	67.	99.	122.	155.	172.	170.	157.	139.	106.	71.	53.	1365.
PREC DEF	54.	67.	99.	122.	155.	163.	104.	77.	104.	95.	71.	34.	1077.
MAI	.00	.00	.00	.00	.00	.05	.39	.51	.25	.10	.00	.35	.21

TENANCINGO YRS 15 ALT 2079 METERS LAT 19 2 LON 99 33

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	SUM OR AV.
MEAN TEMP	12.6	14.1	15.9	17.3	18.5	17.9	17.4	17.1	16.7	16.9	15.3	13.4	16.1
MEAN RS	370.	470.	510.	510.	500.	460.	440.	450.	440.	390.	380.	360.	440.
PRECIP	9.	15.	20.	29.	105.	276.	325.	295.	332.	113.	27.	4.	1550.
PREC DEP	0.	0.	4.	11.	63.	183.	219.	196.	222.	69.	9.	0.	1275.
POT ET	80.	96.	122.	124.	130.	113.	111.	112.	105.	96.	87.	80.	1256.
PREC DEF	80.	96.	119.	113.	66.	-70.	-107.	-84.	-117.	28.	78.	80.	-19.
MAI	.00	.01	.03	.09	.49	1.62	1.97	1.75	2.12	.71	.10	.00	1.02

TENOSIQUE YRS 15 ALT 60 METERS LAT 17 29 LON 91 25

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	SUM OR AV.
MEAN TEMP	23.7	24.8	26.5	29.1	30.1	29.2	28.5	28.8	28.3	27.2	25.1	24.2	27.1
MEAN RS	380.	450.	500.	410.	450.	400.	400.	460.	350.	400.	400.	340.	412.
PRECIP	132.	89.	55.	43.	178.	276.	172.	232.	339.	367.	175.	156.	2214.
PREC DEP	83.	52.	28.	20.	115.	183.	111.	153.	227.	247.	112.	99.	1872.
POT ET	113.	124.	159.	134.	156.	132.	134.	155.	113.	130.	119.	103.	1572.
PREC DEF	31.	73.	131.	114.	41.	-51.	23.	2.	-114.	-117.	7.	4.	-301.
MAI	.73	.41	.18	.15	.74	1.39	.83	.99	2.02	1.90	.94	.97	1.19

TEPEHUANES YRS 15 ALT 1786 METERS LAT 25 20 LON 105 43

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	SUM OR AV.
MEAN TEMP	9.3	12.2	13.4	16.4	19.5	23.0	22.0	21.2	20.3	17.4	13.1	9.9	16.5
MEAN RS	350.	450.	520.	550.	550.	600.	500.	530.	500.	440.	400.	350.	478.
PRECIP	19.	12.	5.	2.	13.	70.	139.	100.	104.	31.	14.	32.	542.
PREC DEP	4.	0.	0.	0.	0.	39.	87.	60.	63.	12.	0.	12.	368.
POT ET	67.	87.	115.	130.	147.	170.	143.	148.	132.	111.	85.	69.	1403.
PREC DEF	64.	87.	115.	130.	147.	131.	56.	88.	69.	99.	85.	56.	1035.
MAI	.05	.00	.00	.00	.00	.23	.61	.41	.48	.11	.00	.18	.26

TABLE 3 CLIMATE AND MOISTURE AVAILABILITY INDICES FOR MEXICO

TEPIC YRS 15 ALT 917 METERS LAT 21 31 LON 104 53

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	SUM OR AV.
MEAN TEMP	17.2	17.9	18.6	20.7	21.5	23.7	23.5	23.5	23.5	23.0	20.7	18.0	20.9
MEAN RS	390.	450.	510.	530.	520.	490.	460.	480.	450.	430.	400.	350.	455.
PRECIP	31.	21.	1.	0.	2.	170.	344.	288.	202.	75.	9.	53.	1196.
PREC DEP	12.	5.	0.	0.	0.	109.	231.	191.	132.	42.	0.	27.	956.
POT ET	97.	104.	133.	142.	146.	142.	137.	142.	129.	126.	105.	89.	1492.
PREC DEF	85.	99.	133.	142.	146.	32.	-94.	-49.	-2.	83.	105.	63.	536.
MAI	.12	.04	.00	.00	.00	.77	1.69	1.34	1.02	.34	.00	.30	.64

TEXCOCO YRS 15 ALT 2215 METERS LAT 19 31 LON 98 52

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	SUM OR AV.
MEAN TEMP	12.5	14.2	16.4	17.9	19.1	18.4	17.6	17.5	17.3	15.8	13.9	12.7	16.1
MEAN RS	370.	460.	500.	500.	500.	450.	440.	450.	440.	390.	370.	350.	434.
PRECIP	6.	7.	12.	22.	60.	135.	153.	150.	139.	55.	20.	9.	768.
PREC DEP	0.	0.	0.	5.	32.	85.	97.	95.	87.	29.	4.	0.	571.
POT ET	80.	95.	122.	123.	132.	113.	111.	113.	107.	91.	81.	76.	1247.
PREC DEF	80.	95.	122.	118.	100.	28.	14.	18.	20.	62.	77.	76.	672.
MAI	.00	.00	.00	.04	.24	.75	.87	.84	.82	.32	.05	.00	.46

TEZIUTLAN YRS 15 ALT 2442 METERS LAT 19 48 LON 97 21

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	SUM OR AV.
MEAN TEMP	11.4	12.5	14.9	17.4	18.1	16.8	15.8	15.9	15.6	14.2	12.4	11.6	14.7
MEAN RS	360.	450.	490.	490.	480.	450.	450.	460.	430.	370.	360.	340.	427.
PRECIP	59.	42.	55.	62.	55.	235.	210.	195.	330.	347.	118.	44.	1752.
PREC DEP	31.	19.	28.	34.	29.	154.	137.	127.	221.	233.	72.	21.	1457.
POT ET	75.	87.	114.	119.	123.	107.	108.	110.	99.	84.	75.	71.	1173.
PREC DEF	44.	68.	85.	86.	95.	-47.	-29.	-16.	-122.	-149.	3.	50.	-284.
MAI	.42	.22	.25	.28	.23	1.44	1.27	1.15	2.23	2.77	.97	.30	1.24

TICUE EL YRS 15 ALT 25 METERS LAT 18 15 LON 101 40

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	SUM OR AV.
MEAN TEMP	27.0	27.1	28.4	28.8	30.1	29.5	30.0	29.6	27.8	29.4	27.4	26.9	28.4
MEAN RS	410.	490.	500.	520.	500.	440.	460.	470.	460.	400.	410.	380.	452.
PRECIP	30.	0.	0.	0.	0.	255.	84.	199.	565.	75.	149.	51.	1411.
PREC DEP	11.	0.	0.	0.	0.	168.	49.	129.	388.	42.	94.	26.	1150.
POT ET	132.	140.	167.	169.	173.	146.	159.	161.	146.	133.	129.	122.	1778.
PREC DEF	121.	140.	167.	169.	173.	-23.	110.	32.	-241.	91.	35.	96.	628.
MAI	.08	.00	.00	.00	.00	1.16	.31	.80	2.65	.32	.73	.21	.65

TIERRA BLANCA YRS 15 ALT 60 METERS LAT 18 20 LON 96 20

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	SUM OR AV.
MEAN TEMP	22.1	23.5	25.7	27.7	29.1	28.7	27.5	28.0	27.6	26.7	24.8	23.2	26.2
MEAN RS	360.	420.	450.	450.	460.	430.	430.	450.	400.	370.	350.	340.	409.
PRECIP	25.	11.	3.	14.	46.	301.	295.	299.	264.	193.	65.	21.	1527.
PREC DEP	7.	0.	0.	0.	22.	201.	197.	199.	175.	118.	35.	4.	1255.
POT ET	103.	113.	141.	143.	156.	140.	140.	149.	127.	119.	104.	100.	1533.
PREC DEF	96.	113.	141.	143.	134.	-61.	-56.	-51.	-48.	1.	68.	96.	279.
MAI	.07	.00	.00	.00	.14	1.44	1.40	1.34	1.38	1.00	.34	.04	.82

TIERRA COLORADA YRS 15 ALT 297 METERS LAT 17 10 LON 99 36

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	SUM OR AV.
MEAN TEMP	26.4	27.1	28.2	28.9	29.9	28.4	27.6	27.7	27.3	27.3	26.7	26.6	27.7
MEAN RS	410.	480.	520.	510.	500.	400.	450.	460.	450.	400.	400.	370.	446.
PRECIP	5.	2.	1.	1.	42.	255.	263.	189.	323.	144.	196.	15.	1433.
PREC DEP	0.	0.	0.	0.	19.	168.	174.	122.	216.	91.	127.	0.	1170.
POT ET	130.	140.	173.	166.	172.	129.	147.	151.	142.	130.	124.	118.	1723.
PREC DEF	130.	140.	173.	166.	153.	-39.	-27.	29.	-74.	39.	-3.	118.	553.
MAI	.00	.00	.00	.00	.11	1.30	1.18	.81	1.52	.70	1.02	.00	.68

TABLE 3 CLIMATE AND MOISTURE AVAILABILITY INDICES FOR MEXICO

TIJUANA YRS 15 ALT 28 METERS LAT 32 29 LON 117 2

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	SUM OR AV.
MEAN TEMP	12.6	13.3	14.1	15.2	16.7	18.4	21.1	21.4	19.6	17.5	15.6	13.0	16.5
MEAN RS	280.	370.	490.	560.	600.	710.	650.	630.	550.	410.	350.	290.	491.
PRECIP	54.	57.	43.	29.	20.	3.	0.	2.	5.	21.	19.	66.	315.
PREC DEP	29.	30.	20.	10.	4.	0.	0.	0.	0.	4.	2.	36.	164.
POT ET	61.	74.	111.	128.	148.	178.	181.	177.	142.	103.	91.	54.	1447.
PREC DEF	33.	44.	91.	117.	144.	178.	181.	177.	142.	99.	78.	27.	1283.
MAI	.46	.41	.18	.08	.02	.00	.00	.00	.00	.04	.03	.57	.11

TLACOLULA YRS 15 ALT 0 METERS LAT 16 57 LON 96 29

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	SUM OR AV.
MEAN TEMP	17.9	19.4	20.6	21.9	22.7	21.9	21.2	21.1	21.1	20.5	18.5	18.0	20.4
MEAN RS	410.	470.	520.	500.	500.	450.	500.	460.	450.	440.	400.	390.	457.
PRECIP	3.	1.	5.	11.	73.	99.	76.	76.	106.	36.	3.	4.	492.
PREC DEP	0.	0.	0.	0.	41.	59.	43.	43.	64.	15.	0.	0.	323.
POT ET	104.	113.	143.	138.	145.	124.	140.	128.	121.	121.	100.	100.	1478.
PREC DEF	104.	113.	143.	138.	104.	65.	97.	85.	57.	106.	100.	100.	1155.
MAI	.00	.00	.00	.00	.28	.48	.31	.34	.53	.12	.00	.00	.22

TLACOTALPAN YRS 15 ALT 31 METERS LAT 18 14 LON 97 57

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	SUM OR AV.
MEAN TEMP	24.9	26.0	26.7	28.1	29.2	28.6	28.3	28.3	27.9	27.4	25.8	25.3	27.2
MEAN RS	350.	450.	500.	480.	490.	430.	450.	450.	430.	390.	370.	340.	427.
PRECIP	46.	10.	10.	6.	34.	117.	124.	93.	265.	204.	125.	43.	1079.
PREC DEP	23.	0.	0.	0.	14.	72.	77.	55.	175.	133.	78.	20.	851.
POT ET	107.	131.	160.	154.	163.	139.	150.	150.	137.	127.	112.	105.	1636.
PREC DEF	85.	131.	160.	154.	149.	68.	73.	94.	-38.	-6.	35.	95.	785.
MAI	.21	.00	.00	.00	.09	.51	.51	.37	1.28	1.05	.69	.19	.52

TLAXCALA YRS 15 ALT 2252 METERS LAT 19 19 LON 98 14

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	SUM OR AV.
MEAN TEMP	12.9	14.2	16.4	17.1	17.9	17.1	16.3	16.2	16.2	15.7	14.5	13.7	15.7
MEAN RS	380.	450.	490.	500.	490.	450.	440.	450.	440.	380.	370.	350.	432.
PRECIP	6.	2.	9.	19.	72.	126.	135.	150.	136.	48.	7.	6.	717.
PREC DEP	0.	0.	0.	3.	41.	79.	84.	95.	85.	24.	0.	0.	525.
POT ET	93.	93.	120.	121.	125.	109.	107.	109.	103.	91.	82.	78.	1220.
PREC DEF	93.	93.	120.	118.	84.	30.	23.	14.	18.	67.	82.	78.	695.
MAI	.00	.00	.00	.02	.33	.72	.79	.87	.83	.26	.00	.00	.43

TLAYACAPAN YRS 15 ALT 1634 METERS LAT 18 57 LON 98 59

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	SUM OR AV.
MEAN TEMP	16.9	18.0	20.1	21.1	22.0	20.9	19.8	19.4	19.2	18.9	17.9	17.2	19.3
MEAN RS	390.	460.	500.	500.	490.	430.	440.	450.	440.	390.	370.	350.	433.
PRECIP	0.	2.	0.	2.	58.	193.	213.	183.	199.	69.	11.	4.	924.
PREC DEP	0.	0.	0.	0.	31.	118.	139.	118.	129.	39.	0.	0.	712.
POT ET	97.	106.	136.	135.	140.	115.	118.	120.	113.	100.	91.	87.	1357.
PREC DEF	97.	106.	136.	135.	109.	-3.	-21.	2.	-16.	61.	91.	87.	646.
MAI	.00	.00	.00	.00	.22	1.03	1.17	.99	1.14	.39	.00	.00	.52

TLAXIACO YRS 15 ALT 1936 METERS LAT 17 15 LON 97 40

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	SUM OR AV.
MEAN TEMP	13.9	15.0	16.0	17.4	18.9	18.7	18.2	18.1	18.2	17.0	14.8	14.2	16.7
MEAN RS	390.	460.	500.	450.	470.	400.	430.	440.	420.	370.	350.	350.	419.
PRECIP	1.	2.	16.	18.	78.	207.	180.	206.	193.	91.	8.	4.	1003.
PREC DEP	0.	0.	1.	2.	45.	135.	116.	134.	125.	54.	0.	0.	783.
POT ET	88.	97.	120.	109.	123.	101.	111.	113.	105.	92.	79.	80.	1217.
PREC DEF	88.	97.	119.	107.	79.	-34.	-5.	-21.	-20.	38.	79.	80.	434.
MAI	.00	.00	.01	.02	.36	1.34	1.04	1.19	1.20	.58	.00	.00	.64

TABLE 3 CLIMATE AND MOISTURE AVAILABILITY INDICES FOR MEXICO

TOLIMAN YRS 15 ALT 1510 METERS LAT 20 55 LON 99 56

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	SUM OR AV.
MEAN TEMP	14.7	16.0	17.1	20.6	22.1	22.7	22.1	21.6	20.5	18.2	15.7	14.7	18.8
MEAN RS	370.	460.	510.	510.	500.	470.	440.	460.	450.	390.	380.	350.	441.
PRECIP	14.	3.	8.	6.	27.	38.	76.	53.	84.	28.	10.	5.	352.
PREC DEP	0.	0.	0.	0.	9.	16.	44.	27.	49.	10.	0.	0.	197.
POT ET	86.	100.	127.	136.	143.	132.	126.	130.	119.	100.	88.	81.	1368.
PREC DEF	86.	100.	127.	136.	134.	116.	82.	103.	70.	91.	88.	81.	1172.
MAI	.00	.00	.00	.00	.06	.12	.35	.21	.41	.10	.00	.00	.14

TOLUCA YRS 15 ALT 2675 METERS LAT 19 17 LON 99 39

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	SUM OR AV.
MEAN TEMP	9.3	11.1	13.0	14.3	14.9	14.4	13.4	13.5	13.4	12.8	11.3	10.3	12.6
MEAN RS	400.	460.	510.	510.	400.	460.	440.	450.	440.	390.	380.	360.	433.
PRECIP	10.	9.	21.	26.	63.	[illegible]	168.	144.	151.	49.	20.	7.	791.
PREC DEP	0.	0.	0.	8.	34.	[illegible]	108.	90.	96.	24.	4.	0.	592.
POT ET	77.	85.	112.	113.	93.	102.	98.	100.	94.	85.	76.	72.	1108.
PREC DEF	77.	85.	112.	104.	59.	18.	-10.	10.	-1.	60.	72.	72.	515.
MAI	.00	.00	.00	.07	.37	.83	1.10	.90	1.01	.29	.05	.00	.53

TONALA YRS 15 ALT 54 METERS LAT 16 5 LON 93 45

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	SUM OR AV.
MEAN TEMP	27.2	27.4	28.5	29.4	29.1	27.1	27.3	27.5	27.2	27.2	27.8	27.2	27.7
MEAN RS	350.	450.	500.	450.	450.	390.	420.	400.	350.	350.	410.	350.	406.
PRECIP	2.	3.	13.	9.	122.	299.	301.	270.	374.	199.	29.	6.	1628.
PREC DEP	0.	0.	0.	0.	75.	199.	201.	179.	252.	129.	10.	0.	1345.
POT ET	114.	132.	167.	148.	153.	122.	137.	131.	110.	114.	130.	114.	1571.
PREC DEF	114.	132.	167.	148.	77.	-77.	-65.	-48.	-142.	-15.	120.	114.	220.
MAI	.00	.00	.00	.00	.49	1.63	1.47	1.37	2.29	1.14	.08	.00	.86

TOPOLO BAMPO YRS 15 ALT 3 METERS LAT 25 36 LON 109 3

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	SUM OR AV.
MEAN TEMP	18.6	19.7	20.1	22.2	25.0	29.1	29.8	29.7	29.7	27.8	24.0	19.7	24.6
MEAN RS	350.	410.	500.	550.	590.	600.	550.	500.	500.	490.	400.	300.	478.
PRECIP	7.	7.	7.	0.	2.	6.	40.	101.	56.	74.	7.	55.	360.
PREC DEP	0.	0.	0.	0.	0.	0.	18.	60.	29.	42.	0.	29.	204.
POT ET	91.	99.	136.	153.	181.	197.	189.	172.	166.	161.	116.	80.	1742.
PREC DEF	91.	99.	136.	153.	181.	197.	171.	111.	137.	120.	116.	52.	1538.
MAI	.00	.00	.00	.00	.00	.00	.09	.35	.18	.26	.00	.36	.12

TULANCINGO YRS 15 ALT 2181 METERS LAT 20 5 LON 98 22

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	SUM OR AV.
MEAN TEMP	11.4	12.8	14.8	16.7	17.4	16.7	16.1	15.9	15.7	14.2	12.6	12.1	14.7
MEAN RS	350.	450.	500.	510.	500.	480.	450.	460.	450.	390.	360.	350.	438.
PRECIP	8.	12.	11.	24.	47.	95.	74.	66.	128.	99.	16.	10.	578.
PREC DEP	0.	0.	0.	7.	23.	56.	42.	36.	79.	52.	1.	0.	401.
POT ET	73.	88.	116.	122.	120.	114.	109.	110.	104.	89.	75.	74.	1200.
PREC DEF	73.	88.	116.	115.	102.	58.	67.	75.	25.	37.	74.	74.	800.
MAI	.00	.00	.00	.05	.19	.49	.38	.32	.76	.59	.02	.00	.33

TUXPAN YRS 15 ALT 14 METERS LAT 20 57 LON 97 24

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	SUM OR AV.
MEAN TEMP	19.5	21.1	22.4	25.6	27.6	28.3	27.9	27.9	27.3	25.4	22.3	19.8	24.6
MEAN RS	330.	390.	490.	500.	500.	490.	450.	470.	450.	390.	350.	340.	427.
PRECIP	40.	26.	26.	38.	87.	201.	174.	168.	306.	223.	53.	39.	1382.
PREC DEP	18.	8.	8.	16.	51.	131.	112.	108.	204.	146.	27.	18.	1124.
POT ET	88.	96.	138.	151.	164.	154.	148.	155.	142.	121.	97.	91.	1546.
PREC DEF	70.	87.	130.	135.	113.	23.	36.	47.	-63.	-24.	70.	74.	422.
MAI	.20	.09	.06	.11	.31	.85	.75	.70	1.44	1.20	.28	.19	.73

TABLE 3 CLIMATE AND MOISTURE AVAILABILITY INDICES FOR MEXICO

TUXTLA GUTIERREZ YRS 15 ALT 536 METERS LAT 16 45 LON 93 6

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	SUM OR AV.
MEAN TEMP	21.6	23.0	24.7	26.6	27.2	25.9	25.4	25.5	25.1	24.3	22.6	20.7	24.4
MEAN RS	350.	450.	500.	450.	450.	390.	420.	400.	350.	350.	400.	350.	405.
PRECIP	0.	1.	1.	6.	75.	235.	175.	155.	201.	91.	4.	6.	947.
PREC DEP	0.	0.	0.	0.	43.	155.	113.	99.	131.	47.	0.	0.	727.
POT ET	99.	119.	153.	139.	146.	119.	131.	125.	104.	106.	112.	97.	1449.
PREC DEF	99.	119.	153.	139.	103.	-36.	18.	26.	-26.	59.	112.	97.	722.
MAI	.00	.00	.00	.00	.29	1.30	.86	.79	1.25	.44	.00	.00	.50

UNION LA YRS 15 ALT 38 METERS LAT 17 58 LON 101 48

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	SUM OR AV.
MEAN TEMP	26.5	26.4	26.9	27.7	28.7	28.9	28.7	28.5	27.9	28.0	27.5	26.6	27.7
MEAN RS	420.	470.	500.	520.	510.	450.	500.	480.	460.	420.	410.	380.	460.
PRECIP	7.	23.	0.	0.	12.	190.	236.	210.	319.	86.	18.	22.	1127.
PREC DEP	0.	6.	0.	0.	0.	123.	155.	137.	213.	50.	2.	5.	691.
POT ET	134.	135.	159.	165.	171.	147.	160.	160.	147.	139.	130.	122.	1776.
PREC DEF	134.	129.	159.	165.	171.	23.	12.	23.	-66.	88.	127.	116.	885.
MAI	.00	.05	.00	.00	.00	.64	.93	.86	1.45	.36	.02	.04	.50

UNION DE TULA YRS 15 ALT 1305 METERS LAT 19 59 LON 104 15

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	SUM OR AV.
MEAN TEMP	20.1	19.9	20.8	21.9	23.3	23.4	21.7	21.4	21.6	21.7	20.6	19.9	21.3
MEAN RS	400.	460.	500.	530.	530.	470.	500.	500.	450.	440.	410.	350.	462.
PRECIP	67.	9.	5.	0.	30.	113.	179.	145.	167.	59.	26.	18.	817.
PREC DEP	37.	0.	0.	0.	11.	69.	115.	92.	107.	31.	8.	2.	615.
POT ET	109.	109.	139.	146.	156.	134.	142.	140.	123.	125.	109.	94.	1526.
PREC DEF	72.	109.	139.	146.	145.	65.	27.	49.	16.	93.	101.	92.	911.
MAI	.34	.00	.00	.00	.07	.52	.81	.65	.87	.25	.08	.02	.40

URES YRS 15 ALT 432 METERS LAT 29 26 LON 110 24

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	SUM OR AV.
MEAN TEMP	15.0	16.6	18.0	20.6	24.5	28.3	29.7	28.8	28.4	24.3	19.0	16.0	22.4
MEAN RS	330.	420.	540.	640.	660.	700.	650.	600.	560.	490.	400.	320.	526.
PRECIP	10.	9.	22.	10.	8.	20.	156.	125.	68.	37.	19.	50.	535.
PREC DEP	0.	0.	6.	0.	0.	4.	100.	78.	37.	16.	3.	25.	362.
POT ET	77.	93.	138.	170.	201.	225.	223.	202.	191.	148.	102.	77.	1837.
PREC DEF	77.	93.	132.	170.	201.	221.	124.	124.	143.	132.	99.	52.	1475.
MAI	.00	.00	.04	.00	.00	.02	.45	.39	.21	.11	.03	.32	.20

URUAPAN YRS 15 ALT 1610 METERS LAT 19 25 LON 101 58

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	SUM OR AV.
MEAN TEMP	16.0	17.0	19.6	21.5	22.4	21.8	21.1	20.8	20.3	19.7	17.5	16.6	19.5
MEAN RS	400.	470.	510.	510.	500.	460.	450.	460.	450.	400.	400.	370.	448.
PRECIP	16.	21.	7.	4.	32.	273.	347.	329.	406.	179.	37.	21.	1683.
PREC DEP	1.	5.	0.	0.	12.	161.	233.	221.	274.	115.	16.	12.	1395.
POT ET	96.	105.	136.	139.	144.	126.	125.	127.	119.	107.	98.	91.	1415.
PREC DEF	95.	101.	136.	139.	132.	-55.	-107.	-94.	-156.	-8.	81.	79.	20.
MAI	.01	.05	.00	.00	.09	1.43	1.86	1.74	2.31	1.07	.17	.13	.99

VALLADOLID YRS 15 ALT 21 METERS LAT 20 41 LON 88 13

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	SUM OR AV.
MEAN TEMP	22.1	23.0	24.7	26.6	27.2	26.5	26.7	26.5	26.3	25.2	23.1	22.7	25.1
MEAN RS	350.	440.	520.	500.	500.	500.	500.	510.	450.	400.	400.	340.	451.
PRECIP	55.	28.	27.	74.	120.	148.	140.	160.	179.	145.	49.	56.	1181.
PREC DEP	20.	9.	9.	42.	74.	93.	88.	102.	115.	92.	24.	29.	943.
POT ET	100.	116.	152.	155.	162.	154.	160.	163.	138.	124.	114.	99.	1644.
PREC DEF	72.	107.	150.	113.	88.	61.	72.	60.	23.	32.	89.	69.	701.
MAI	.28	.08	.06	.27	.46	.60	.55	.63	.83	.74	.21	.30	.57

TABLE 3 CLIMATE AND MOISTURE AVAILABILITY INDICES FOR MEXICO

VALLARTA PUERTO YRS 15 ALT 1 METERS LAT 20 37 LON 105 15

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	SUM OR AV.
MEAN TEMP	22.7	22.5	23.0	24.5	26.2	27.3	27.8	27.9	28.2	28.1	26.3	24.0	25.7
MEAN RS	370.	450.	500.	530.	530.	490.	500.	500.	450.	450.	400.	350.	460.
PRECIP	17.	55.	2.	0.	9.	207.	347.	359.	332.	138.	15.	7.	1488.
PREC DEP	2.	28.	0.	0.	0.	135.	233.	242.	223.	87.	1.	0.	1220.
POT ET	108.	118.	146.	156.	168.	154.	164.	165.	145.	149.	123.	105.	1700.
PREC DEF	106.	89.	146.	156.	168.	20.	-69.	-77.	-78.	62.	122.	105.	491.
MAI	.01	.24	.00	.00	.00	.87	1.42	1.47	1.54	.58	.01	.00	.72

VENUSTIANO CARRANZA YRS 15 ALT 0 METERS LAT 17 49 LON 95 49

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	SUM OR AV.
MEAN TEMP	21.2	22.3	23.1	26.0	27.7	27.2	26.6	26.6	26.4	25.1	22.7	21.4	24.7
MEAN RS	340.	450.	480.	450.	450.	450.	420.	450.	390.	390.	350.	340.	413.
PRECIP	39.	28.	18.	36.	71.	286.	370.	419.	406.	319.	101.	60.	2153.
PREC DEP	18.	9.	3.	15.	39.	190.	249.	283.	274.	213.	60.	32.	1817.
POT ET	95.	117.	141.	137.	148.	141.	134.	144.	120.	120.	98.	95.	1492.
PREC DEF	77.	107.	138.	122.	109.	-49.	-115.	-139.	-154.	-93.	38.	64.	-326.
MAI	.18	.08	.02	.11	.27	1.34	1.85	1.97	2.28	1.78	.61	.33	1.22

VERACRUZ YRS 15 ALT 15 METERS LAT 19 12 LON 96 8

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	SUM OR AV.
MEAN TEMP	21.2	21.9	22.9	24.9	26.7	27.3	27.0	27.2	26.9	26.1	23.8	22.0	24.8
MEAN RS	325.	435.	520.	520.	597.	619.	502.	560.	528.	505.	427.	340.	490.
PRECIP	23.	16.	7.	20.	53.	245.	346.	300.	345.	153.	88.	25.	1622.
PREC DEP	6.	1.	0.	4.	27.	161.	233.	200.	232.	97.	52.	8.	1340.
POT ET	91.	112.	151.	154.	191.	195.	162.	182.	164.	160.	123.	97.	1783.
PREC DEF	85.	111.	151.	150.	165.	33.	-71.	-18.	-67.	63.	72.	89.	443.
MAI	.07	.01	.00	.03	.14	.83	1.44	1.10	1.41	.61	.42	.08	.75

VICTORIA YRS 15 ALT 321 METERS LAT 23 44 LON 99 8

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	SUM OR AV.
MEAN TEMP	15.7	18.1	21.3	24.5	26.4	27.0	27.4	27.9	25.9	23.3	19.6	15.5	22.7
MEAN RS	320.	420.	490.	510.	540.	550.	510.	570.	470.	410.	330.	300.	449.
PRECIP	36.	24.	20.	39.	126.	121.	104.	68.	198.	108.	42.	15.	903.
PREC DEP	15.	7.	4.	17.	79.	75.	63.	37.	129.	66.	20.	1.	693.
POT ET	76.	100.	137.	150.	172.	172.	166.	171.	143.	121.	85.	71.	1565.
PREC DEF	61.	93.	133.	133.	93.	97.	103.	134.	14.	55.	65.	70.	872.
MAI	.20	.07	.03	.11	.46	.43	.38	.22	.90	.54	.24	.01	.44

VICTORIA VILLA YRS 15 ALT 0 METERS LAT 21 21 LON 100 13

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	SUM OR AV.
MEAN TEMP	15.3	17.2	18.9	20.9	22.5	21.9	20.9	20.8	20.6	19.0	16.7	15.9	19.2
MEAN RS	370.	450.	510.	520.	500.	490.	450.	470.	450.	390.	360.	360.	444.
PRECIP	12.	10.	15.	11.	34.	87.	83.	56.	92.	25.	12.	6.	444.
PREC DEP	0.	0.	1.	0.	14.	51.	48.	29.	55.	8.	0.	0.	280.
POT ET	87.	102.	134.	142.	145.	135.	125.	130.	120.	103.	86.	86.	1393.
PREC DEF	87.	102.	133.	142.	131.	84.	77.	101.	65.	95.	86.	86.	1114.
MAI	.00	.00	.01	.00	.10	.38	.39	.23	.46	.09	.00	.00	.20

VILLA ALDAMA YRS 15 ALT 408 METERS LAT 26 30 LON 100 26

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	SUM OR AV.
MEAN TEMP	12.3	16.0	20.4	22.2	24.9	27.2	28.7	28.9	27.1	23.0	18.8	12.9	21.9
MEAN RS	300.	400.	440.	520.	520.	610.	600.	550.	490.	420.	310.	330.	457.
PRECIP	25.	9.	14.	21.	31.	38.	59.	36.	77.	34.	27.	11.	381.
PREC DEP	7.	0.	0.	5.	12.	17.	31.	15.	44.	13.	9.	0.	223.
POT ET	64.	87.	120.	144.	160.	192.	201.	185.	154.	123.	78.	72.	1591.
PREC DEF	57.	87.	120.	140.	148.	175.	171.	170.	110.	109.	69.	72.	1358.
MAI	.11	.00	.00	.03	.07	.09	.15	.09	.29	.11	.12	.00	.14

TABLE 2 CLIMATE AND MOISTURE AVAILABILITY INDICES FOR MEXICO

VILLAHERMOSA YRS 15 ALT 10 METERS LAT 17 59 LON 92 55

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	SUM OR AV.
MEAN TEMP	22.2	23.8	24.9	26.8	28.2	28.2	28.0	28.4	27.6	26.7	24.7	22.9	26.0
MEAN RS	330.	420.	490.	410.	450.	400.	400.	460.	350.	400.	390.	340.	403.
PRECIP	140.	100.	46.	46.	89.	204.	194.	195.	272.	292.	142.	181.	1902.
PREC DEP	88.	60.	22.	22.	53.	133.	126.	126.	180.	195.	90.	117.	1592.
POT ET	95.	113.	150.	127.	149.	128.	132.	153.	111.	129.	115.	99.	1503.
PREC DEF	6.	54.	128.	105.	97.	-5.	6.	27.	-69.	-66.	26.	-17.	-89.
MAI	.93	.53	.15	.17	.35	1.04	.95	.82	1.62	1.52	.79	1.17	1.06

XILITLA YRS 15 ALT 0 METERS LAT 21 24 LON 99 0

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	SUM OR AV.
MEAN TEMP	15.6	17.6	19.5	22.5	23.5	24.2	23.9	24.0	23.1	21.4	18.3	16.4	20.8
MEAN RS	360.	440.	500.	530.	500.	430.	450.	480.	450.	390.	370.	350.	442.
PRECIP	66.	56.	71.	65.	113.	345.	358.	321.	744.	263.	100.	37.	2538.
PREC DEP	36.	29.	40.	35.	69.	232.	240.	215.	511.	174.	60.	16.	2164.
POT ET	86.	100.	133.	148.	149.	143.	135.	144.	128.	109.	92.	85.	1453.
PREC DEF	49.	72.	94.	113.	79.	-89.	-106.	-71.	-383.	-65.	32.	70.	-710.
MAI	.42	.29	.30	.24	.46	1.62	1.78	1.49	4.00	1.59	.65	.18	1.49

ZACAPU YRS 15 ALT 2000 METERS LAT 19 45 LON 101 45

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	SUM OR AV.
MEAN TEMP	11.4	12.9	15.4	17.4	19.1	19.1	17.7	17.2	16.9	15.2	13.0	11.9	15.6
MEAN RS	400.	460.	510.	520.	500.	460.	450.	460.	450.	400.	400.	370.	448.
PRECIP	14.	5.	9.	8.	30.	102.	199.	192.	168.	67.	23.	19.	836.
PREC DEP	0.	0.	0.	0.	11.	61.	129.	124.	108.	37.	6.	4.	633.
POT ET	83.	91.	121.	126.	132.	117.	114.	115.	108.	94.	85.	78.	1264.
PREC DEF	83.	91.	121.	126.	121.	56.	-15.	-9.	0.	57.	79.	74.	631.
MAI	.00	.00	.00	.00	.08	.52	1.13	1.08	1.00	.39	.07	.05	.50

ZACATECAS YRS 15 ALT 2611 METERS LAT 22 47 LON 102 34

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	SUM OR AV.
MEAN TEMP	9.3	10.5	12.7	14.9	16.7	16.0	14.1	14.6	13.8	13.1	11.3	10.1	13.1
MEAN RS	350.	460.	520.	530.	520.	470.	450.	490.	450.	400.	390.	360.	448.
PRECIP	10.	5.	2.	2.	23.	52.	90.	59.	76.	22.	15.	11.	368.
PREC DEP	0.	0.	0.	0.	6.	27.	53.	32.	43.	5.	1.	0.	211.
POT ET	67.	83.	113.	119.	128.	110.	102.	111.	98.	98.	78.	71.	1168.
PREC DEF	67.	83.	113.	119.	122.	83.	49.	79.	55.	92.	77.	71.	957.
MAI	.00	.00	.00	.00	.05	.24	.52	.29	.44	.06	.01	.00	.19

ZAMORA YRS 15 ALT 1632 METERS LAT 19 59 LON 102 18

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	SUM OR AV.
MEAN TEMP	16.2	17.6	19.7	21.9	23.2	22.6	20.9	20.8	20.8	20.3	18.7	17.2	20.0
MEAN RS	400.	470.	500.	520.	500.	470.	460.	490.	450.	410.	400.	370.	453.
PRECIP	16.	7.	13.	7.	33.	158.	191.	162.	153.	56.	14.	19.	829.
PREC DEP	1.	0.	0.	0.	13.	101.	117.	104.	97.	29.	0.	3.	618.
POT ET	97.	107.	134.	143.	147.	132.	127.	135.	120.	112.	101.	92.	1449.
PREC DEF	96.	107.	134.	143.	134.	31.	11.	32.	23.	83.	101.	89.	832.
MAI	.01	.00	.00	.00	.09	.76	.92	.77	.81	.26	.00	.04	.43

ZAPOTITLAN YRS 15 ALT 3 METERS LAT 18 33 LON 94 49

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	SUM OR AV.
MEAN TEMP	22.0	22.7	23.3	24.4	26.0	26.5	26.2	26.2	26.3	25.7	24.1	23.0	24.7
MEAN RS	340.	390.	420.	450.	460.	430.	440.	450.	400.	400.	340.	330.	404.
PRECIP	169.	104.	99.	50.	80.	363.	376.	366.	549.	535.	328.	374.	3394.
PREC DEP	109.	63.	60.	25.	46.	244.	253.	246.	374.	365.	220.	252.	2935.
POT ET	97.	103.	124.	132.	145.	133.	139.	143.	123.	125.	99.	97.	1460.
PREC DEF	-12.	40.	64.	107.	99.	-111.	-114.	-104.	-251.	-239.	-121.	-155.	-1475.
MAI	1.12	.61	.48	.19	.32	1.84	1.81	1.73	3.05	2.91	2.22	2.61	2.01

TABLE 3 CLIMATE AND MOISTURE AVAILABILITY INDICES FOR MEXICO

ZIMAPAN YRS 15 ALT 1720 METERS LAT 20 45 LON 99 23

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	SUM OR AV.
MEAN TEMP	16.0	18.2	20.3	21.4	21.6	20.4	20.2	20.0	19.3	18.5	16.4	15.5	19.0
MEAN RS	360.	450.	500.	510.	500.	470.	440.	460.	450.	390.	380.	350.	438.
PRECIP	10.	2.	6.	9.	36.	78.	41.	47.	87.	43.	9.	7.	375.
PREC DEP	0.	0.	0.	0.	15.	45.	19.	23.	51.	20.	0.	0.	217.
POT ET	87.	105.	136.	139.	141.	124.	120.	125.	115.	101.	90.	93.	1366.
PREC DEF	87.	105.	136.	139.	126.	79.	101.	102.	64.	81.	90.	93.	1148.
MAI	.00	.00	.00	.00	.11	.36	.16	.18	.44	.20	.00	.00	.16

ZINAPECUARO YRS 15 ALT 1839 METERS LAT 19 50 LON 100 48

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	SUM OR AV.
MEAN TEMP	15.4	16.4	18.1	20.2	21.6	21.4	19.9	19.1	19.1	18.1	17.0	16.0	18.5
MEAN RS	400.	470.	510.	510.	500.	460.	450.	460.	440.	390.	400.	370.	447.
PRECIP	15.	6.	4.	5.	25.	137.	144.	193.	149.	43.	15.	22.	758.
PREC DEP	0.	0.	0.	0.	7.	46.	91.	125.	94.	20.	0.	5.	560.
POT ET	95.	104.	131.	134.	141.	125.	121.	121.	112.	100.	96.	89.	1370.
PREC DEF	94.	104.	131.	134.	134.	79.	31.	-4.	18.	80.	96.	84.	810.
MAI	.01	.00	.00	.00	.05	.69	.75	1.03	.84	.70	.00	.06	.41

ZIRANDARO YRS 15 ALT 192 METERS LAT 18 29 LON 100 59

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	SUM OR AV.
MEAN TEMP	26.5	28.2	30.7	31.4	33.2	31.4	29.3	28.6	28.9	29.0	28.0	26.7	29.2
MEAN RS	420.	470.	500.	510.	500.	450.	450.	470.	450.	400.	400.	380.	450.
PRECIP	4.	1.	0.	4.	13.	157.	240.	191.	183.	57.	16.	11.	877.
PREC DEP	0.	0.	0.	0.	0.	100.	159.	124.	118.	30.	1.	0.	669.
POT ET	134.	141.	173.	176.	185.	155.	153.	157.	145.	135.	128.	122.	1804.
PREC DEF	134.	141.	173.	176.	185.	55.	-5.	34.	26.	105.	127.	122.	1134.
MAI	.00	.00	.00	.00	.00	.64	1.07	.79	.82	.22	.01	.00	.37

ZITACUARO YRS 15 ALT 2064 METERS LAT 19 22 LON 100 23

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	SUM OR AV.
MEAN TEMP	14.3	15.5	17.4	19.3	20.4	19.0	17.4	17.2	17.4	17.2	15.8	14.7	17.1
MEAN RS	400.	460.	510.	510.	500.	460.	450.	460.	440.	390.	400.	370.	446.
PRECIP	9.	12.	8.	6.	37.	173.	216.	185.	209.	55.	28.	15.	963.
PREC DEP	0.	0.	0.	0.	16.	111.	141.	120.	137.	35.	9.	1.	747.
POT ET	91.	99.	128.	131.	137.	117.	113.	115.	107.	97.	93.	96.	1313.
PREC DEF	91.	99.	128.	131.	121.	6.	-28.	-5.	-30.	62.	83.	95.	567.
MAI	.00	.00	.00	.00	.11	.95	1.25	1.04	1.28	.36	.10	.01	.57

LITERATURE CITED

ASCE Technical Committee on Irrigation Water Requirements of the Irrigation and Drainage Division. 1973. Consumptive Use of Water and Irrigation Water Requirements. American Society of Civil Engineers. 215 pp.

Hargreaves, George H. 1972. The Evaluation of Water Deficiencies. Age of Changing Priorities for Land and Water. American Society of Civil Engineers. Irrigation and Drainage Specialty Conference, Spokane, Washington. September 26-28. pp. 273-290.

Hargreaves, George H. 1974. Estimation of potential and crop evapotranspiration. Transactions of the ASAE 17(4):701-704.

Hargreaves, George H. 1974. Climatic Zoning for Agricultural Production in Northeast Brazil. Utah State University CUSUSWASH 74-A148. 6 pp. with map.

Hargreaves, George H. and Stephan Allan. Computation of Evapotranspiration and Radiation. Unpublished.

Lof, George O. G., John A. Duffie, and Clayton O. Smith. 1966. World Distribution of Solar Radiation. Engineering Experiment Station Report No. 21. Solar Energy Laboratory, University of Wisconsin. 59 pp. with maps.

Pruitt, W. O. 1966. Empirical Method of Estimating Evapotranspiration Using Primarily Evaporation Pans. Evapotranspiration and Its Role in Water Management. ASAE Conference Proceedings.

Pruitt, W. O. February 8, 1974. Personal Communication. Department of Water Science and Engineering, University of California, Davis, California.

Wernstedt, Fredrick L. 1972. World Climatic Data. Climatic Data Press. Lemont, Pennsylvania. 522 pp.

USE AND INTERPRETATION OF LIMITED HYDROLOGIC DATA

Martin M. Fogel[1]

INTRODUCTION

There appears to be fundamental conflict of interest between the collector and analyzer of hydrologic data and the agriculturist or engineer that is in need and uses such data. The data analyst wants to collect more and more years of observations in order to improve on the accuracy of his product. The user must make decisions now even though the data may be considered inadequate.

By itself hydrologic data is useless. Properly analyzed, however, it can provide the basis for the planning, designing, and operating systems involving our most important renewable natural resource. This presentation discusses analyzing hydrologic data for the purpose of the making of decisions for the control and utilization of water when the basic hydrologic data is limited. While much of the material is found in hydrology textbooks, a good deal is new material published in recent scientific journals.

HYDROLOGIC ANALYSIS FOR FLOOD CONTROL

Since the planning and design of water resources systems are concerned with future events whose time or magnitude cannot be forecast, it is necessary to resort to statements of probability or frequency, which asks, for example, in what period of time will a storm of a specified magnitude be equalled or exceeded. Selection of the appropriate level of probability for design, that is, the risk that will be acceptable, rests on economic or policy grounds.

This section presents a brief discussion on the analysis of hydrologic data for flood control where streamflow data is first, available, and then is limited or very often nonexistent.

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Frequency analysis of streamflow data

If streamflow data were available for a minimum of 30 or 40 years, it would be relatively simple to determine, in probabilistic terms when a specified volume of flow or rate of flow will be equalled or exceeded. Standard hydrology textbooks present such methodology.

Briefly, this procedure starts with the data which, needless to say, must be relevant, adequate and accurate. Most flood studies are concerned with peak flows so that the set of data normally consists of the maximum flow rate for each year of record. The data is then fit to a theoretical frequency distribution such as the log-Pearson Type III which has been recommended for use by United States federal agencies for flood analysis. If the fit is considered acceptable, confidence is gained in extrapolating beyond the limits of the data. For example, experience may determine that small dams be designed to control streamflow that has a probability of being equalled or exceeded once in 50 years. Since the record length may be only 30 years, some means of reliably estimating the peak flow rate for longer time periods is needed. Fig. 1 illustrates a graphical analysis of fitting hydrologic data to a particular frequency distribution.

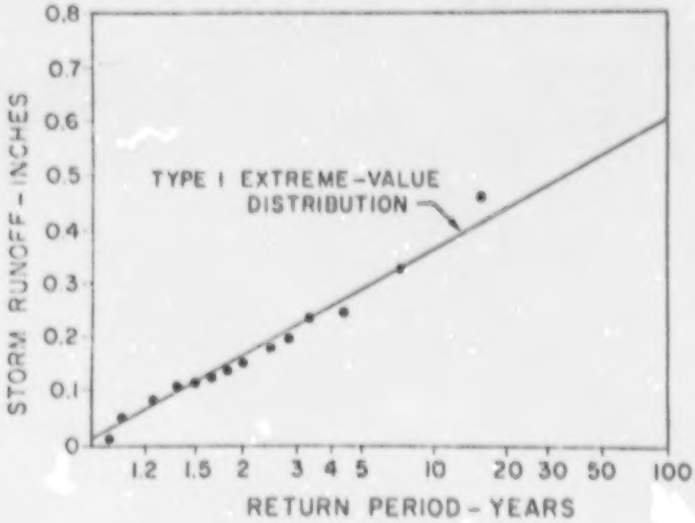


Fig. 1. Extreme-value distribution of annual maximum storm runoff volumes.

Probability precipitation model

In many instances, streamflow data may not be available, but precipitation records are, usually at least for a short time period. For these cases, the use of a rainfall-runoff relationship, together with an analysis of precipitation data, can provide the means for estimating streamflow for a specified probability or return period. For example, if it has been determined that a given storm precipitation, say 60 mm, has a probability of being equalled or exceeded once in 50 years. The probability would be 1/50 or 2 percent and the return period 50 years. Then, if this amount were used in a rainfall-runoff formula, the calculated runoff would also have a 2 percent probability or a 50-year return period.

To obtain the storm precipitation probability in the above example, at least 30 years of record are generally needed to make a reliable analysis. On the other hand, if the length of record is not sufficient, there is another method for determining the return period of a given storm precipitation. The use of probability precipitation models allows estimates to be made with a minimum of data, in some cases even less than five years.

The University of Arizona has developed a probabilistic precipitation model which has been found to adequately represent conditions in semiarid regions. The first step is to divide the year into seasons according to the type of precipitation. In Arizona, for example, convective storms usually occur during the months July through either September or October which are intense, of short duration, and affect small areas. On the other hand, frontal precipitation, which has characteristics markedly different than convective storms, occurs during the remainder of the year. These two storm types are analyzed separately.

The precipitation model requires frequency distributions for the number of storms per season and the amount of precipitation per storm. Based on experience in semiarid areas, it has been found that a particular distribution (Poisson) can be used to describe the occurrence of storms in a season. With an estimate of the average number of such events in a season, the probability of any other number of storms can be determined (see Fig. 2). The other distribution required concerns the amount of precipitation per storm which is shown in Fig. 3.

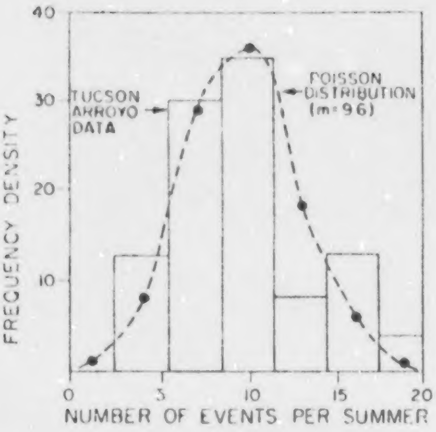


Fig. 2. Poisson distribution of number of runoff-producing events from convective storms.

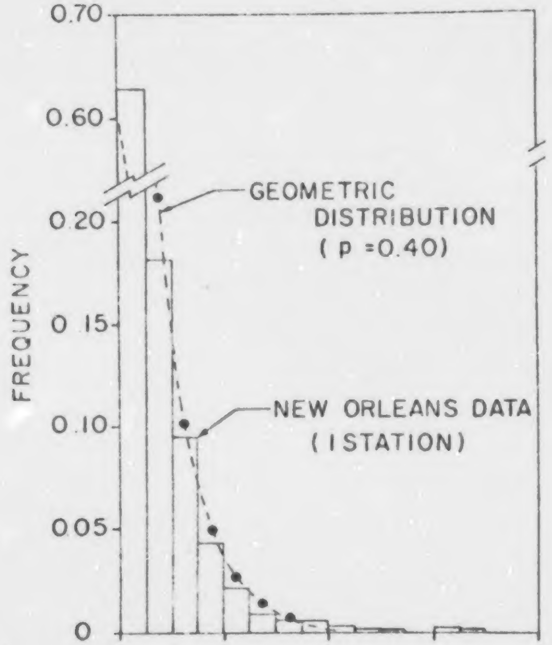


Fig. 3. Frequency distribution of storm rainfall per event.

With the above two distributions it now becomes possible to obtain information needed by the users of hydrologic data in planning designing or operating water systems. The return period for a given storm can be calculated as can the probability of receiving a specified total amount of precipitation for the entire season. Also, a synthetic sequence of future precipitation data can be obtained (see Fig. 4).

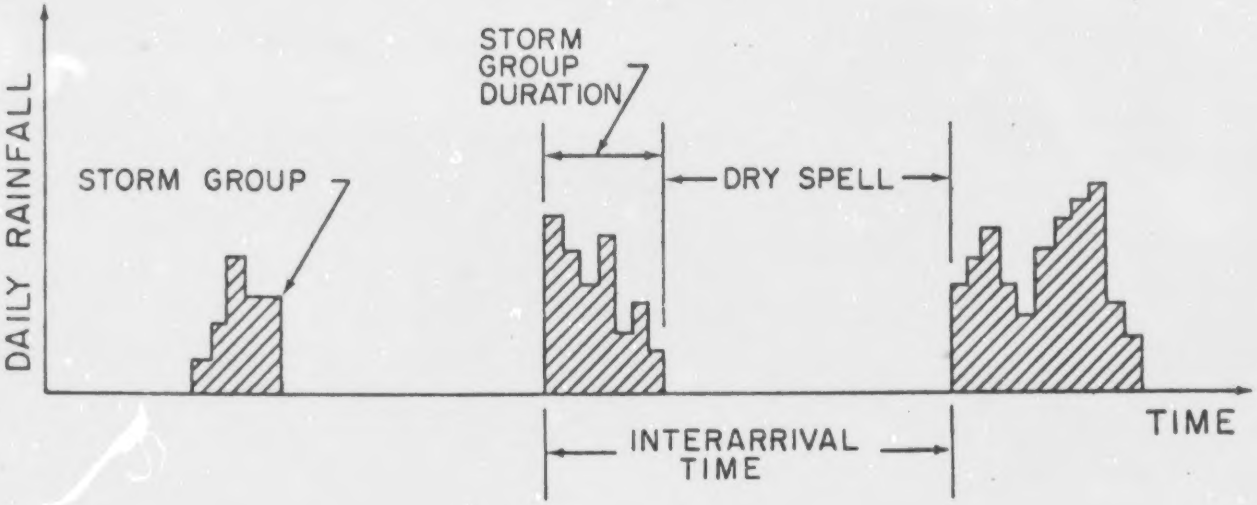


Fig. 4. Synthetic sequence of precipitation data.

RAINFALL UNCERTAINTY: ITS AFFECT ON AGRICULTURE

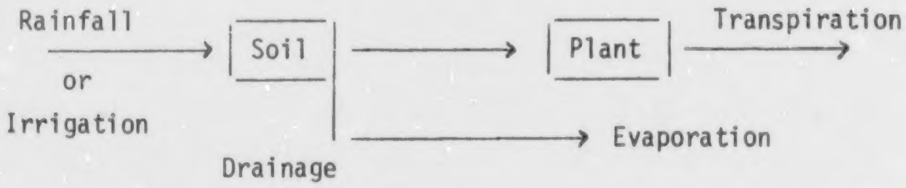
Living in an environment plagued with water shortages, one becomes acutely aware of the rainfall regime, the relatively infrequent occurrence of storms coupled with small amounts of rainfall per storm. Once in a while, however, an individual storm may produce a flood of great magnitude, but this may be followed by weeks or months of drouth. The important item here in considering agricultural production, is that the timing or sequencing of the storms is as important as the amount of rainfall. This section discusses the use of the previously developed precipitation model as input into basic plant-soil systems as a basis for understanding and predicting the production of agricultural crops. The adaptability of certain crops to a particular rainfall regime may also be determined in this manner.

Moisture stress and crop yield

The amount of water required by crops for maximum production is generally well known, Methods of calculating, or tables of consumptive use, or evapotranspiration values are readily found in the literature. Under these conditions, there is little or no moisture stress. In the case of dryland or rainfed agriculture, biologists have shown that the effect of a moisture at different physiological stages of development will have different effects on the harvested yield. In addition, a stress in one growth period will affect the subsequent growth of the crop. Unfortunately, these interrelationships have not been quantified to any great extent as of now. Fortunately, current research is attempting to characterize the effects of water stress on crop yields. The emphasis is mainly in connection with irrigated crops to determine the best time to apply water and how much. The same techniques, however, could be used in dryland or rainfed agriculture.

Soil moisture simulation models

Rainfall and irrigation replenishes water in the soil reservoir while evapotranspiration and vertical drainage deplete the available supply. A simple system is shown below.



The problem is that neither the inputs to, nor outputs from, the system are constant throughout the growing season. In order to determine the effects of a moisture stress on crop yield, it is first necessary to understand the basic relationships in the plant-soil-water system.

If a plant is to extract moisture from the soil, it must do so against tensions which hold water in the soil. As this soil water level falls, the moisture tension increases very rapidly. The rate of water use by a crop not only depends on the soil water level, but also on the atmospheric or evaporative demand which is a function of meteorological conditions. Fig. 5 illustrates the relationship between relative evapotranspiration rates as a function of the atmospheric demand and the soil water level.

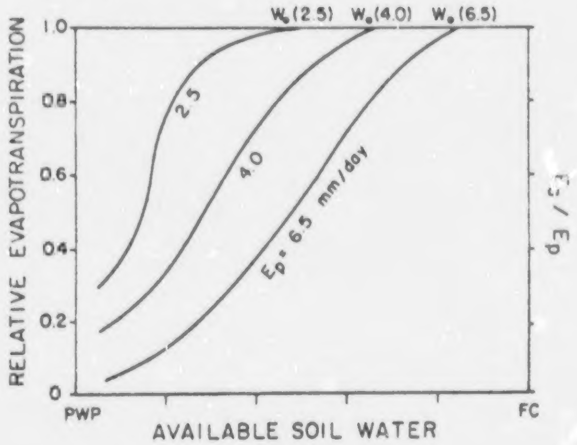


Fig. 5. Relative evapotranspiration rates as a function of potential demand and soil water content.

With this means for determining the actual rate of water used by crops, the next step is to incorporate the inputs into the system, the rainfall. Since the system inputs and outputs are continually varying, some means of looking at the system in a time-dependent framework is necessary. Fig. 6 illustrates a proposed method for determining plant water stress, whereas Fig. 7, in a simplified example, compares this stress for a high crop yield against a low crop yield.

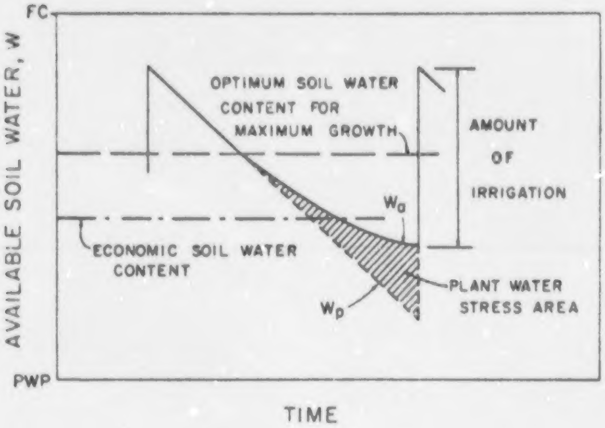


Fig. 6 Plant water stress as a function of soil water content.

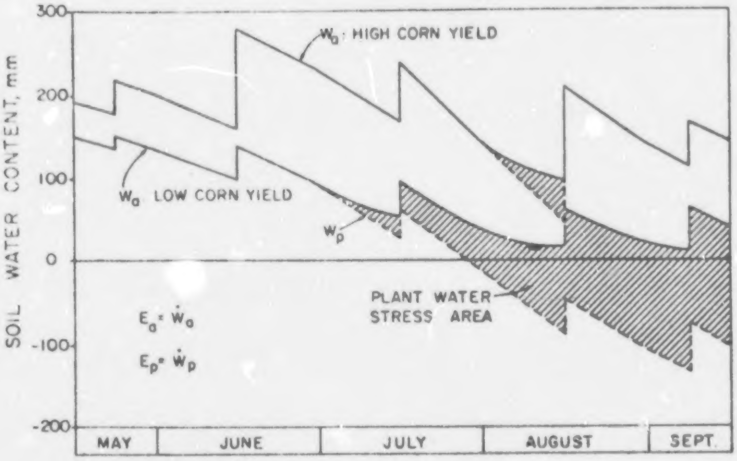


Fig. 7 Simplified version of seasonal fluctuation of soil water content for two extreme cases of corn production.

RELIABILITY OF SURFACE WATER

Since surface runoff is the direct result of precipitation, both are highly variable quantities in semiarid regions. The dependability of surface water decreases with the drier zones. This section discusses means for analyzing hydrologic data in reference to the development of surface water supplies.

Flow duration and mass curves

Where streamflow data is readily available for a number of years, flow duration and mass curves are means for determining the reliability of streamflow. The flow duration curve is simply a cumulative frequency curve that shows the percent of time during which specified discharges were equalled or exceeded in any given period. It provides a convenient means for studying the flow characteristics of streams and for comparing one basin with another. Flow duration curves can be prepared for daily flows, mean monthly flows or mean annual flows. Fig. 8 shows a histogram of flows from which a flow duration curve is made.

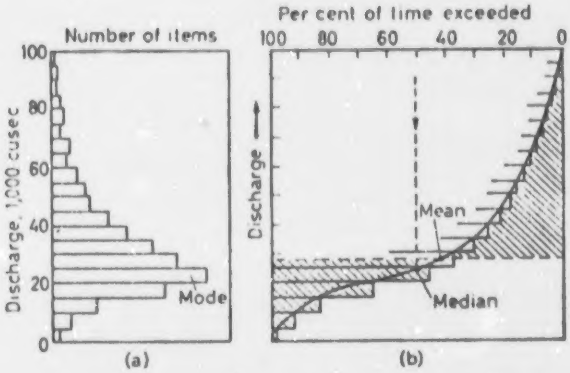


Fig. 8. Frequency and flow duration curves.

The mass curve is a graphical tool to detect trends in streamflow. It is a convenient device to determine storage requirements that are needed to produce a certain dependable flow from a reservoir (Fig. 9).

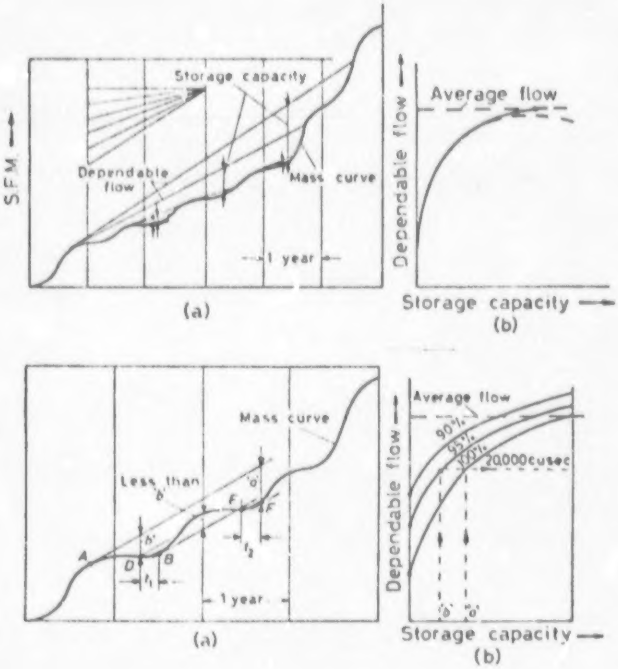


Fig. 9. Mass curves of streamflow.

Runoff simulation model

In many instances, only precipitation data is available for a particular watershed. The use of rainfall-runoff relationship allows each precipitation event to be converted into runoff. Historical precipitation data can be used as input into the runoff formula or the precipitation model, as previously described, can be used to generate a synthetic series of precipitation events. Whereas in the plant-soil-water system, the infiltrated portion of the rainfall serves as input, in this case the runoff portion is of interest. A method for estimating runoff from rainfall will be presented in a later presentation.

LITERATURE

Bidwell, V. J. 1972. Agricultural response to hydrologic drought. Hydrology paper no. 53. Colorado State University. Ft. Collins. 25 pp.

Duckstein, L., M. M. Fogel and C.C. Kisiel. 1972. Stochastic model of runoff-producing rainfall for summer-type storms. Water Resources Research 8(3): 327-350.

Duckstein, L., M. M. Fogel and J. L. Thames. 1972. Elevation effects on rainfall: a stochastic model. Journal of Hydrology 18(1): 21-35.

Fogel, M. M. and L. Duckstein. 1970. Prediction of convective storm runoff in semi-arid regions. Proc. Symposium on Representative and Experimental Watersheds, IASH, New Zealand. Publication no. 96: 465-478.

Fogel, M. M., L. Duckstein and C. C. Kisiel. 1974. Optimal control of irrigation water application. Automatica 10(6): 579-586.

Kao, S.E., L. Duckstein and M. M. Fogel. 1971. A probabilistic model for winter rainfall. Paper presented at AGU National Fall Meeting. San Francisco, California.

Kisiel, C.C., L. Duckstein and M. M. Fogel. 1971. Analysis of ephemeral flow in arid lands. Journal Hydraulics Div. ASCE 97(HY 10): 1699-1717.

Kuiper, E. 1965. Water resources development-planning, engineering and economics. Butterworth and Co. Washington. 483 pp.

Linsley, R. K., M. A. Kohler and J. L. H. Paulus. 1975. Hydrology for engineers. 2nd ed. McGraw-Hill Book Co. New York. 482 pp.

VEGETATION MANIPULATION ON RANGELANDS

Phil R. Ogden[1]

INTRODUCTION

Any decision to manipulate vegetation on a watershed must be based on an understanding of precipitation patterns, range sites, potential productivity of each range site on which vegetation changes are to be made, and an estimate of successional or retrogressional trends which may result from different management strategies. Previous discussions concerning range sites, range condition, precipitation dependability, and livestock grazing influences provide the basic information necessary to make decisions with regard to vegetation manipulation. Much of the information necessary for making proper decisions must be provided by research.

MANIPULATING VEGETATION WITH GRAZING ANIMALS

With proper grazing management, vegetation condition on sites within a watershed may be improved to provide both improved cover and an increase in desirable plant species. In addition to this general improvement which can be accomplished by good management, there are cases where livestock may be utilized to influence changes in plant species. Cattle, sheep, and goats have forage preference differences and these differences may be further accentuated by seasonal forage preference differences among livestock classes. If research data are available on livestock preference by different seasons and plant growth requirements are known, grazing systems sometimes can be designed to benefit or reduce the vigor of a given plant species. There are limitations, however. If the undesirable plants are long-lived, such as woody species, and are not palatable to livestock, grazing animals will not eliminate these plants once they have become established.

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MANIPULATING VEGETATION WITH FIRE

Plant species are extremely variable as to their response to fire, and there is a seasonal variability in fire damage to plants. For instance, creosotebush (Larrea tridentata) in southern Arizona showed higher mortality from burning in June and July than when burned at other seasons (White 1968). Creosotebush mortality was influenced most by the more intense and longer burning fires in June and July compared to other seasons.

In general, shrubby species are more damaged by fire than herbaceous species, but some shrubs may sprout after being burned. Research data, or management experience over time, must provide the information on how individual species respond to fire in order to plan efficient use of fire in vegetation manipulation.

A major cost of burning is the herbage which must be conserved for use as fuel rather than as forage. This cost must be included in economic evaluations of burning. Also, any recommended burning treatment must be coordinated with grazing management programs so that fuel is provided for the fire, and forage is provided for livestock. Burning must also be coordinated with precipitation patterns so that burned watershed areas are not devoid of cover when the probability is great for high intensity storms.

CHEMICAL CONTROL OF UNDESIRABLE PLANTS

In southern Arizona, diesel oil applied to the base of individual mesquite trees (Prosopis juliflora) killed 90% of the plants (Martin 1957). This is an effective method of shrubby plant control if the shrub species to be controlled is susceptible and if the plants are scattered.

Foliar application of herbicides may also be used to eradicate undesirable species. Low rates of 2,4,5-T sprayed twice in successive years has been effective in controlling mesquite (Cable and Tschirley 1961). Success with foliar herbicides is very seasonal dependent, as the leaves must be at a growth stage so that they have adequate surface area, yet have not developed a cuticle layer which reduces absorption of the chemical.

For the best plant kill, the herbicide must then be translocated to the roots of the plant. Type of herbicide, rates, and season of application studies are necessary to determine the most effective and economical control conditions. Granular herbicides applied to the ground at the base of plants to be killed are less sensitive to time of application but are dependent on moisture conditions. Effective amounts are dependent on species to be controlled, soil conditions, and moisture. Intensive research programs are needed to make correct recommendations on herbicidal control of undesirable plants on a watershed. These research programs should also include monitoring of herbicides in water from a watershed and the effects of the herbicide on plants other than the ones to be controlled.

Chemical control of undesirable plants has the greatest chance of being a useful method of vegetation manipulation when one or more species can be reduced in abundance to allow other native species to increase. If reseeding is necessary because there is a lack of desirable species, then mechanical control which will also provide a seedbed may be the most desirable control method.

MECHANICAL TREATMENTS TO REMOVE UNDESIRABLE PLANTS

There are numerous methods of mechanical control of undesirable plants which may be utilized to manipulate vegetation. The selection of a method is dependent on species to be removed, soil, labor and equipment available, costs, and the kind of seedbed which is prepared if seeding is to follow mechanical control.

Chopping or grubbing individual plants by hand is effective if plants to be controlled are not too numerous and if relatively cheap labor is available. These methods are not effective in preparing a seedbed if reseeding of the area is necessary.

Cabling or chaining is accomplished by dragging a heavy chain or cable between two crawler-type tractors. This method is good for large trees or shrubs which will either be uprooted by the chain or break off and not sprout. Small, limber shrubs or trees are not well controlled by this method. Soil is disturbed but may not be loosened enough to be a good seedbed on some soils.

Bulldozing individual trees is a method which may be used on nearly all sites except steep slopes. It is best used on large shrubs or small trees. This method may be utilized where plants are scattered or where plants are dense. The cost is greater with denser vegetation.

Rootplowing is an effective control of woody plants. A rootplow can be adjusted for depth to cut below the bud zone. The tilt can be adjusted to lift plants out of the soil and to prepare a good seedbed. For small brush on soils which are not too rocky, discing may provide effective control of vegetation and preparation of a seedbed. Pitting may also be accomplished along with, or following plowing, to improve seeding success on certain range sites.

Many mechanical treatment research studies and trials have been conducted throughout the world. The application of results from one area to another depends on characteristics of species to be controlled, soils, and local economic and technical considerations. Any research program on mechanical control treatments, as with any research program, should be based on a critical review of research which has been accomplished in view of possible adaptation to local situations. Then select the most promising methods for trial studies on local range sites.

RESEEDING

Reseeding success is dependent upon many factors, and research should be aimed at identifying the combination of these factors which contribute to the greatest probability of success for various range sites. There are sites with low rainfall and/or soil conditions which provide a very low chance of successful reseeding. These sites should be identified as well as those sites which can be successfully seeded.

Successful seeding requires that the following conditions be met:

1. A suitable site with soil and precipitation conditions which provide a reasonable probability for success. In general, higher precipitation is required to establish plants on clay soils than on more sandy soils.
2. The plant species to be seeded must be adapted to the site. Selecting adapted ecotypes within a species may also provide

an extra measure of success on some sites. Wright and Streetman (1960) discussed methods of selecting for drought tolerance, and Wright has selected seedlings of Lehmann lovegrass (Eragrostis lehmanniana) for drought tolerance which has provided higher seedling survival in southern Arizona trials.

3. Preparation of a seedbed which adequately controls existing vegetation and provides for rapid infiltration of moisture into the soil. A loose, irregualr seedbed is often desirable on range seeding operations.
4. Sow adequate seed to insure a successful stand but not to the point of being wasteful. Seeding approximately one million viable seeds per acre is a rough estimate of seeding intensity. For small-seeded species, like Lehmann lovegrass, the seeding rate is less than one pound per acre, and this pound per acre rate increases as seed becomes larger.
5. Provide for proper depth of seed coverage. The smaller the seed, the shallower it should be seeded. Broadcasting of small seed on loose seedbeds is often adequate, but drilling is recommended for large seeds and crusted seedbeds.
6. Seed at the season when favorable moisture and temperature combine for the longest possible favorable germination and seedling growth period.
7. Provide for protection of seedlings until they have become well established. In very dry sites, this may be for three or more growing seasons.
8. Provide for proper grazing after the reseeded area is grazed again. Reseeding is expensive and can only be justified if it provides returns in forage and for watershed protection over many years.

Vegetation manipulation may be accomplished by many methods. Each method has some advantages and disadvantages for any given situation. The researcher is usually faced with the task of selecting some alternatives which appear best for his area and then conducting trials to determine which are the best for his specific conditions.

LITERATURE CITED

Cable, Dwight R. and Tschirley, F. H. 1961. Responses of native and introduced grasses following aerial spraying of velvet mesquite in southern Arizona. J. Range Manage. 14:155-159, illus.

Martin, S. Clark. 1957. To control mesquite economically start early and keep at it. Ariz. Cattlelog 12(6):22-26, illus.

White, Larry D. 1968. Factors affecting susceptibility of creosotebush (*Larrea tridentata* (D.C.) Cov.) to burning. Ph.D. Dissertation, Univ. of Arizona. 96 pp., illus.

Wright, Neal and Streetman, L. J. 1960. Grass improvement for the Southwest relative to drought evaluation. Arizona Agric. Expt. Sta. Tech. Bull. 143. 16 pp.

WATERSHED REHABILITATION
CULTURAL AND MECHANICAL CONSIDERATIONS

Glen E. Stringham[1]

INTRODUCTION

One of the characteristics of a watershed in poor condition, and in need of rehabilitation, is the transportation of sediment in the runoff water. This sediment comes from the land surface, from debris which accumulates in the stream channel, and from mass wasting of stream banks. If the watershed is to be properly rehabilitated, the sediment transport, or erosion, must be controlled. Since water is the cutting and transporting medium, and since its power to cut and carry sediment is a function of its velocity and volume, all efforts to control erosion, therefore, must be directed at the control of the velocity and volume of water which moves across the watershed.

Methods of controlling water on watersheds can be lumped into three broad categories. First, control by vegetation; second, control by proper tillage practices; and third, by use of mechanical structures which control the velocity and volume of flowing water.

It is the technique by which these methods can be used to control runoff water that will be discussed in this paper.

VEGETATIVE CONTROL

Anyone who has ever been caught in a heavy rainstorm has felt the sting of falling raindrops. When these raindrops strike the surface of a bare soil, they contain sufficient force to dislodge small soil particles and set them in motion, resulting in a general down-stream migration of the soil surface (Wischmeier 1958). One of the important contributions of a good watershed vegetative cover is the protection from direct raindrop impact it gives to the soil. The grassblades, leaves, bushes, stems, and other plant materials absorb the tremendous impact energy of the falling drops much the same as shock absorbers absorb the impact forces of wheels moving over a rough road. Thus, when the rain reaches the surface of the soil, its velocity is greatly reduced, the impact forces are much smaller, fewer soil particles are dislodged, and the watershed surface is much more stable.

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A second method by which plant growth and vegetative covers retard erosion is through binding together of the soil particles by the plant roots. The root system of a healthy plant forms a microscopic mesh in the soil which tends to keep the soil particles in place rather than permit them to move freely. Furthermore, growth cycles of the plants add organic matter to the soil needed for the formation of soil aggregates. These aggregates are much more stable than single particles and, hence, are more resistant to erosion.

The third method by which a good vegetative cover controls erosion is that the plant materials simply get in the way of moving water. To the thin sheet of water moving across the surface of a watershed, grasses, twigs, plant stems, roots, pebbles, and sticks are obstacles to its flow; hence, velocity at which it travels is much less than it would be without the cover. With the reduction in velocity, comes the associated erosion control.

Not only does vegetative cover obstruct the movement of water over the surface of the watershed, it also reduces the quantity of water which moves. When falling rain beats on bare soil, the smaller particles tend to move in around the larger particles and form a seal which prevents water from soaking into the surface. By protecting the soil from the beating action, a good vegetative cover prevents this sealing action, permitting water to soak deeper into the soil. Furthermore, roots of a growing plant penetrate the soil surface and form small channels along which water trickles into the soil profile. Thus, more water is taken from the surface. In addition, because the plants obstruct the flow of water and hold it on the watershed longer, it is in contact with the soil surface longer. Hence, greater quantities will soak into the surface. Therefore, a good vegetative cover not only reduces the velocity of the water movement, but also reduces the quantity to be handled because more water filters into the sub-surface layers; hence, there is less water to be controlled on the surface.

TILLAGE CONTROL

Tillage of watersheds can both retard and accelerate soil erosion so must be used wisely. Tillage has a tendency to break down soil aggregates and to destroy surface residues both of which stabilize soils, so watershed tillage practices must be used which minimize these destructive effects.

On the positive side of watershed tillage is the preparation of a proper seed bed for the establishment of a vegetative cover. It is often difficult, if not impossible, to establish such covers without tillage. Tillage also creates minute pockets which trap and hold water and sediment in place longer, and creates a loose soil mulch on the surface with a relatively high intake rate enabling more water to infiltrate the soil.

Tillage practices for proper management of watersheds can be divided into two general groups; those which pertain to agricultural watersheds and those which pertain to rangeland watersheds.

Tillage Practices for Agricultural Watersheds

One of the most universal practices in the tillage of agricultural lands, is to plow a field parallel to fence lines. When this is done, there are, inevitably, areas where the plow furrows will run up and down the watershed slope. These furrows form ideal collection channels for rainwater, and since the slope is steep, water velocities are high and erosion occurs. Therefore, one of the major conservation tillage practices for agricultural watersheds is to perform all cultivation operations parallel to field contours thus creating level or mildly sloping channels which will hold the water in place or convey it to a safe outlet at low velocities. If row crops are to be grown on these watersheds, the furrows should be planted parallel to the contours to prevent forming channels up and down the slope in which the water will collect and runoff.

A second tillage practice for control of water on agricultural watersheds is to use a crop rotation. This means that one year the watershed may be planted to grain, the second to alfalfa, the third to some row crop, and then back to a grain or corn crop, etc. When this is done, each crop adds different residues to the soil and tends to keep it in better tilth and less susceptible to erosion than if the same crop were grown every year. One problem with this technique is that there are times when the whole field will be barren of any vegetative cover and will be very susceptible to surface erosion. Strip cropping, a technique wherein alternate strips of the field are planted to different crops, i.e., one strip may be alfalfa, the next strip corn, and the next strip fallow, helps to avoid this problem. In a field which is strip-cropped, the width of each strip will vary according to the slope of the watershed and the equipment being used, but will generally vary between 50 and 150 ft. (Schwab 1966). In this way, there are no large areas barren of vegetative cover. Hence, there is less apt to be severe erosion on any one strip.

Another tillage practice often used to protect the watershed is the creation of a vegetative mulch on the surface (Schwab 1966, Moldenhauer 1929). For example, if a grain crop has been harvested, rather than plow the field and turn the stubble under, it is often better to use a disk or a chisel plow to loosen up the soil surface and kill weeds but leave the stubble on the surface. The stubble sticking up through the surface of the soil, dissipates the energy of falling rain and provides the roughness and binding properties needed to keep the soil in place. Such mulches are very effective in controlling erosion. A more recent, and very effective, tillage practice is to plant a crop into the residue of the preceeding one without tilling the ground first (Moldenhauer 1969). Weeds are controlled with chemicals. All residues of the preceding crops are left on the soil surface to provide the protection necessary to prevent erosion.

Tillage Practices for Rangeland Watershed

One of the characteristics of a rangeland watershed in poor condition is the poor vegetative cover which exists. Tillage practices for rangeland, therefore, should be designed to do two things: (1) to help establish a vegetative cover and (2) to help control runoff from the watershed. Both of these aims are complimentary. If water can be held on the watershed, it provides a better environment for establishment of a good vegetative cover. On the other hand, a good vegetative cover reduces the flow of water.

In the past 35 years, the problem of maintaining the water on the watershed has been intensively studied and several successful techniques have been developed. One such tenchique is known as pitting (Anderson 1949); Moldenhauer 1969, Barnes 1960, Wright 1972) wherein small shallow pits are dug in the surface of the watershed. These pits range from 3 to 6 feet in length and from 8 to 12 inches in depth. These pits form small reservoirs all over the surface of the watershed to trap water which subsequently soaks into the soil for use by vegetation.

Another method which has been effectively used is contour furrows (Wright 1972, Hubbard 1953, Barnso 1966). In this process, small furrows varying in depth from 4 to 12 inches and spaced up to 5 feet apart have been plowed on the contour across the watershed surface. These furrows form miniature terraces which hold the water in place until it seeps into the soil surface. Studies have indicated that such furrows are effective in aiding the revegetative process if their spacing is kept to less than 5 feet. Beyond that there is very little vegetative change except right at the furrow. It is important that such furrows be plowed on the contour or otherwise they become drainage ditches which concentrate the water and may cause erosion rather than prevent it. Constructing the furrows parallel to the contours is a very difficult process and one of the disadvantages of the method. The effectiveness of such contour furrows is greatly enhanced if small dikes are made across the furrows at intervals of 4 to 40 feet. The furrows then become small basins and if one section should break, water from adjacent sections does not drain out through it; hence, the water is kept dispersed on the watershed.

A third successful technique has been the creation of miniature fallow strips across the watershed (Wright 1972). These are strips about 5 feet wide, parallel to the contour and cultivated to destroy unwanted vegetation, soften the surface, and prepare a seed bed. The original vegetation is kept between the strips until the new vegetation is properly established. Then new strips are tilled and planted and the process continues until the entire watershed has been rehabilitated. Conventional tillage equipment can be used for this process.

MECHANICAL CONTROL

For the purpose of this paper, mechanical control will be defined as those methods and structures which require careful engineering design and special equipment for construction. These structures are specifically designed to modify slopes, to control the velocity and direction of water flow, to trap and hold water in terrace channels, small ponds, and the soil surface, and to deliberately retard the flow of water as it moves off the watershed. These structures also include those designed for sediment control, i.e. to provide catchment areas for sediment once it has begun to move, and to provide settling basins to allow sufficient time for suspended particles to settle out and not move with the water.

Functional Considerations

There are some functional considerations which must be kept in mind in the design of water control structures. First, and foremost, is they must control the velocity of water. Very few soils can withstand velocities in excess of two meters per second, and a few will erode at velocities approaching one-half meter per second. On the other hand, velocities much less than the soil can withstand require larger channels than needed, and sometimes slopes which produce velocities greater than can be tolerated must be traversed and special structures are needed. Therefore, design velocities depend upon the particular soil type and field conditions encountered on the watershed. The basic principle, however, is velocity control.

A second functional consideration is that stream sizes must be kept within controllable limits. The greater the quantity transported down a given slope, the greater will be the stream velocity and, hence, the greater will be the erosive force. Therefore, a fundamental principle is to keep the streams small.

A third consideration is the provision of safe outlets for all structures which will safely convey water from the watershed. These outlets are usually some type of waterway, either natural channels where erosive potential is low or manmade channels where the banks and bed are stabilized to handle the required flows.

and it is that area including the trench that will be referred to as the terrace. A terrace, then, has two functions: (1) to divide up the watershed and, hence, the quantity of water which must be controlled by any given channel, and (2) to provide for storage and the slow release, either to an outlet channel or the groundwater of water as it moves off the contributing area.

Terraces are generally referred to in two ways: one, with reference to its slope and the other, with reference to its shape. With reference to the slope of a terrace, they are referred to as level terraces or graded terraces. Level terraces are built on the contour and are designed to store all of the water which runs off from the contributing area and retain it within the terrace trench. They are, in essence, long thin storage reservoirs. All water which enters them is retained until it seeps away into the groundwater basin below. Since their purpose is storage and since the contributing area to the terrace trench is relatively uniform, the cross-sectional area of the terrace must also be uniform. Such being the case, there is little flow of water from one location to the other and no sediment movement along the axis of the terrace trench. Any sediment which runs from the contributing area above the terrace is trapped in the trench and does not move from the watershed.

Graded terraces are terraces built just slightly off the contour so as to have a gentle gradient along the trench which makes them waterways for moving the water they collect towards the terrace outlet. The grade of such terraces is such that the velocity of the water is relatively slow and, hence, no erosion occurs within the terrace trench itself. Any sediments which are carried into the terrace from the contributing area are deposited in the trench. Since graded terraces are designed to be conveyance channels, the shape of them will not be constant. The head end of the terrace can be smaller than the outlet end as it will carry less water. A common practice is to divide the total length of the terrace into three or four sections and build each section large enough to carry the maximum amount of water expected at the outlet of each section. Thus, the channel size may vary along its length.

Terrace shapes can be grouped into three general categories: broad base terraces, conservation bench terraces, and simple bench terraces.

Since all structures, and even the watersheds themselves, require maintenance from time to time, it is necessary in rehabilitation designs to consider methods of access. These will include trails, roads, and airstrips, all of which create erosive hazards. Such areas must be carefully designed to prevent them from becoming focal points of erosion on an otherwise well managed watershed.

Design Considerations

A prime consideration in the design of water control structures is the quantity of water which must be handled. For watershed rehabilitation, an intense hydrologic study is generally necessary. Such factors as the intensity, duration, quantity of rainfall, the surface area and soil type of the watershed, and its general topography msut be considered. From this information, the quantity of runoff, its rate of collection, and the peak flows which must be handled can be predicted and the required degree of control determined. Other design considerations include the location of existing water courses, types of structures needed, material available at the construction site, and the tentative location of access roads.

Mechanical Control Structures--Watershed

Mechanical control structures for watershed rehabilitation can be considered in two broad groups. Those pertaining directly to the watershed and those which pertain to the stream channels. Those pertaining to the watershed will be considered first.

Terraces--Terrace Trench

In the context of this paper, a terrace trench is defined as a large trench with sloping sides, constructed parallel to the contour, or at a slight grade thereto, which divides a watershed into smaller sized microwatersheds for the purpose of controlling water. Dirt from the trench is thrown up on the downstream side so the trench will collect and trap the water as it runs down the surface. The area between successive terrace trenches is the watershed area which that particular trench must control

Basically, a broad base terrace is one where the terrace ridge is constructed by moving earth from the up-stream side of the ridge line and depositing the dirt on the downstream side. Slopes of the ridge are flat, generally less than 4:1, which is enough to be crossed with equipment. The flat slopes make the ridge base very broad; hence, its name, "broad base terrace."

A conservation bench terrace is one in which the channel up-slope from the terrace ridge is extended to a considerable width, the bed of which is flat and has zero grade parallel to the axis of the terrace. When water runs off from the contributing area, it is trapped in the conservation trench and filters into the soil of a large land area.

When bench terraces are used, the watershed is literally benched, in that the water storage, or the forage areas, are perfectly flat and the strip between the terraces is steep. Thus, a watershed which has been benched looks like a series of large stair steps. Bench terracing is generally used on very steep slopes.

Motor graders, bulldozers and earth-moving scrapers are the equipment most commonly used for the construction of terrace ridges. Terrace ridges can be constructed by making successive passes with a moldboard or disk plow and throwing the earth onto the ridge line. This, however, is a rather slow process but is adequate for small watersheds or where larger equipment is not available.

Grassed Waterways

One convenient method of conveying water down the steep slope of a watershed is through a grassed waterway. Such channels are simply broad shallow channels whose sides and channel bed are stabilized by a sod forming grass. The most common shapes of grassed waterways are triangular, trapezoidal, and parabolic. To be effective in retarding flow, waterways must be broad to prevent concentrating the water over a narrow strip and shallow to reduce velocities and gain maximum resistance to flow from the grass. Maximum slopes for grassed waterways will vary depending upon the type and condition of the grass and the type of soil on which it is growing.

Another reason for making channels broad and shallow is the need to cross them with equipment. This consideration is particularly important in agricultural watersheds but also is significant on range land, for waterways often need to be crossed with equipment used for watershed management and maintenance.

Pipe Channels

A rather recent development in watershed rehabilitation and erosion control has been the use of a combination of level terraces and pipe drain channels. With this system, terraces trap the water from the contributing area and hold it until it can be slowly released through a pipe drain to a safe outlet area. The inlet structure from the terrace to the pipe is a small standpipe. An orifice in the standpipe controls the flow from the terrace into the drain pipe and prevents overloading. Without the control, if a series of terraces were drained by a single pipeline, it would be possible for flow from the upper terraces to fill the pipe and even cause water to come back up through the lower inlet structures and dump water into the lower terraces resulting in overtopping and failure of the structure itself. Details for the design of such structures can be found in Beasley (1972).

Mechanical Control Structures--Channel

One of the major sources of sediment removed from watersheds is from the bed and banks of gullies and stream channels by which they are dissected. If such watersheds are to be rehabilitated, control over the flow of water in these channels must be established.

Drop Structures

One of the first steps in stabilizing erosion within stream channels is to control the channel gradient. Drop structures which allow for extreme changes in gradient at controllable localized points can be installed at carefully predetermined locations down the channel. The excess energy present at these structures is carefully controlled and wasted in energy dissipators on the downstream side of the structure, from which the water leaves at non-erosive velocites. For drop structures to be effective, they must be spaced so that each structure will control the grade between it to the preceding upstream structure. In this manner water velocity, and hence erosion, is controlled between structures.

Drop structures can be made of steel, concrete, or wood. The materials used will often depend on the accessibility of the structure as it is often difficult to get materials transported to the site over the intervening terrain. Wood structures probably have the shortest life, but the material is readily transportable. Steel structures, if properly coated with galvanizing metal or plastic resins, have a long life and are very effective for small structures. Concrete is perhaps the most durable but also the most difficult to get to remote places. It generally has to be poured on-site, which requires the availability of aggregate, cement, and water at the point of installation.

In small gullies and stream channels, which are inaccessible to heavy equipment and for bringing in construction materials, small drop structures can be made of rock, rubble, or from brush. Rock-rubble structures are built by merely taking and piling rocks in the stream channel. If rocks too large to be moved during high flows are available, then the piles need not be bound in place, otherwise they should be held in place by a wire mesh or piling materials. Even though rock-rubble structures are porous and water will flow through them, energy is lost in the process and water must build up behind them which gives the channel needed grade control.

Brush dams or drop structures can be built by driving two parallel rows of posts across the channel, stretching a mesh wire along the posts, and filling the slot in between with brush. The wire mesh is there to hold the brush in place and the brush serves the same purpose as the rock structures do in dissipating the energy and in controlling the grade of the channel. Such structures, however, are rather temporary and provisions need to be made later to stabilize the entire channel.

Small Dams and Retention Basins

If the volume of water handled in a stream is too large to permit channel stabilization, it is necessary to reduce the flow. Flow reduction can be done by building small retention basins along the stream channel which trap and store the water and silt during high flows and release the water at a rate which can be handled in a stabilized channel. These retention basins usually exist behind small dams constructed across the channel at appropriate locations. Often one dam near the head of a gully or stream will adequately control the flow.

For retention basins to be successful, they must have a main outlet to control normal flow rates and conduct the discharge to a safe escape way. Therefore, when a flood hits the stream channel, the combination of inflow, outflow and storage will control the stream flow below the dam to within controllable limits. Emergency spillways must be provided in the event that a storm greater than can be controlled by the structure occurs, otherwise the dam may fail resulting in increased damage in the downstream section of the channel.

Several types of spillway and outlet works can be constructed for small retention basins. One of the more common is known as a drop-inlet. A drop-inlet is merely a verticle stand pipe in the reservoir connected to a horizontal discharge pipe leading to the downstream side of the dam. When the water reaches the lip of the stand pipe, it drops into the system and flows out through the outlet channel. Thus, the name, drop-inlet. Emergency spillways for small dams, however, are usually overflow devices. Emergency spillways are designed to carry water around the structure and back into the stream channel with a minimum of damage. Since overflow events are rather rare, the long-term damage caused by overflow spillways is not great. The important concern is to be sure that the outlet of the overflow spillway conveys the water safely around the dam so that it will not be destroyed.

SUMMARY

In summary, then, rehabilitation of an eroding watershed begins with water control. Control can be achieved on a watershed with a good vegetative cover, tillage practices adapted to particular slopes, careful location of access roads, and terraces and grassed waterways. These techniques and devices will reduce the volume and velocity of water moving against the erodable surface of the watershed. Once the water leaves the watershed and collects in stream channels, it can be controlled in naturally erosion-resistant channels or channels with specially constructed drop structures, small dams and retention basins. Combinations of these structures and tillage practices can, if properly installed and managed, provide the necessary water control which will provide for the watershed's rehabilitation.

LITERATURE

Anderson, D. and A. R. Swanson. 1950. Machinery for Seedbed Preparation and Seeding on South Western Ranges. Jour. of Watershed Management 2:64-66.

Barnes, O. K. 1950. Mechanical Treatment on Wyoming Range Land. Jour. of Range Management 3(3):198-203.

Beasley, R. P. 1972. Erosion and Sediment Pollution Control. Iowa State University Press. Ames, Iowa.

Branso, F. A., R. F. Miller, and I. S. McQueen. 1966. Contour Furrowing, Pitting, and Ripping on Rangelands of the Western United States. Jour. of Range Management 19(4):182-190.

Hubbard, W. A. and S. Smoliak. 1953. Effect of Contour Dykes and Furrows on Short Grass Prairie. Jour. of Range Management 6(1):55-62.

Moldenhauer, W. C. and M. Amemiya. 1969. Tillage Practices for Controlling Cropland Erosion. Jour. of Soil and Water Cons. 24(1):19-21.

Schwab, G. O., R. K. Frevert, T. W. Edminster, and K. K. Barnes. 1966. Soil and Water Conservation Engineering. 2nd ed. John Wiley & Sons.

Wight, J. R. and F. H. Siddoway. 1972. Improving Precipitation--Use Efficiency on Rangeland by Surface Modification. Jour. of Soil and Water Cons. 27(4):170-174.

Wischmeier, W. H. and D. D. Smith. 1958. Rainfall Energy and Its Relation to Soil Loss. Trans. Am. Geophys. Union. 39:285-291.

WATER CONSERVATION PRACTICES FOR DRYLAND FARMING

K. G. Brengle[1]

INTRODUCTION

"Dryland Farming" is a catch-all term often used to describe any type of farming that is not irrigated. It is necessary to put climatic limitations on the term in order to define the type of agriculture being discussed. The first limitation must, of course, be precipitation.

Usually dryland farming is considered to exist in semiarid regions, but again this term is used to describe widely different areas. In general, a limit for maximum annual average precipitation can be set at about 500 mm for areas receiving summer precipitation, it is less for most winter precipitation areas. This maximum is strictly arbitrary, but there is some justification in selecting this value since, in most summer rainfall areas receiving 500 mm or less annual precipitation, cultural practices primarily designed for semiarid crop production become prevalent. All regions receiving 500 mm annual average precipitation are not equally capable of producing dryland crops. As the annual average precipitation decreases from 500 mm, the differences in productivity between areas becomes more pronounced.

Johnson, Van Doren, and Burnett (1974) use the Thornthwaite P-E index line of 32 as the boundary between subhumid and semiarid zones. The P-E index was designed to take into account the temperature factor in precipitation effectiveness.

In reality, the amount of precipitation received annually is not the most important factor in temperate zone, dryland areas. Annual distribution, i.e., winter precipitation vs. summer precipitation, largely affects the stability of crop production at a given precipitation level. The type of primary precipitation, snow vs. rain, and rainfall intensity also have an effect on the stability of agricultural production in these areas.

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The mean annual temperature and the amount of velocity of wind are other climatic factors that can have a controlling influence on crop production. The crop season temperature is probably more important than the annual average, but temperatures during other parts of the year have an influence on water conservation. Wind is of importance in both evaporation and evapotranspiration. The former affects the efficiency of soil water storage, and the latter affects the water use efficiency of the crop.

These climatic factors and the interactions between them are the principal factors that determine the "effective precipitation." The effective precipitation can be defined as the percentage of the annual rainfall available for plant use.

The dryland farming areas of the United States will be used in this discussion for comparison of different types of dryland areas and cultural practices (Figure 1). It should be kept in mind that these are temperate zone regions and direct comparison with dry sub-tropic or tropic regions will not be applicable. A brief description of some of these regions is necessary in order to understand both the problems encountered in crop production and the practices applied to overcome these problems.

The Great Plains of North America is one of the largest dryland agricultural regions in the world, comprising about 450,000 square miles. Within the continental United States, it extends from Texas to the Canadian border with its eastern limit at approximately the 98th Meridian and its western edge bordering on the Rocky Mountains.

Great Plains agriculture is often referred to in general terms; however, there are actually several distinct regions in so far as agricultural production is concerned. The arbitrary division of the southern, central, and northern Great Plains regions is based primarily on moisture-temperature relationships. Differences in altitude from east to west affects crop adaptability due to the effect on the length of the frost-free season within a given region, especially in the central and northern regions. These differences in longitude, latitude, and altitude are accompanied by differences in soils, type and amount of precipitation, and evapotranspiration rates. About 70-75 percent of the precipitation occurs from April to September in all sections of the Great Plains. The annual

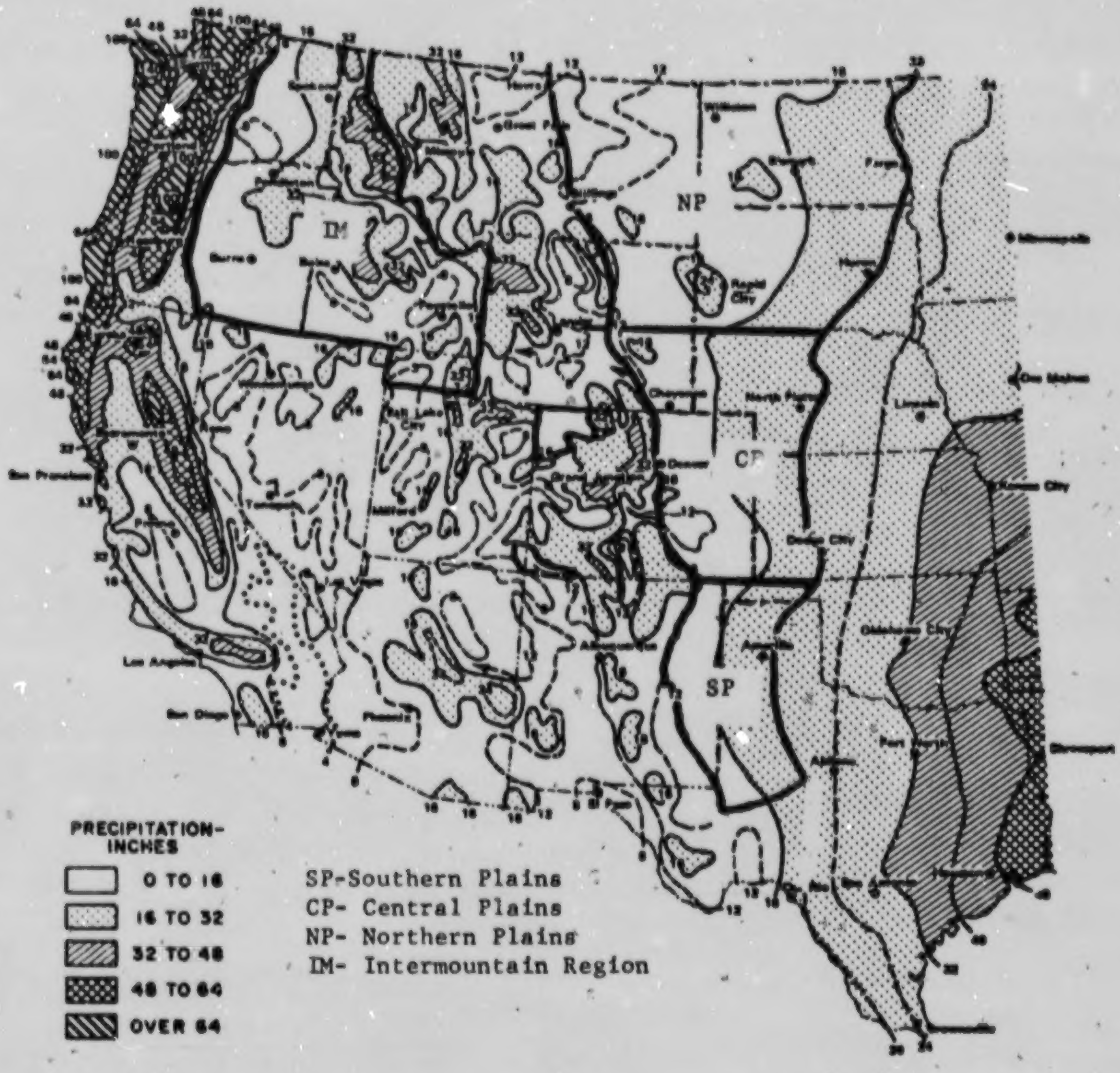

IM
NP
CP
SP
San Francisco
Los Angeles
San Diego
Salt Lake City
Denver
Rapid City
North Platte
Dodge City
Oklahoma City
Amarillo
Fort Worth
Kansas City
Des Moines
Minneapolis
Shreveport
PRECIPITATION-INCHES
0 TO 16
16 TO 32
32 TO 48
48 TO 64
OVER 64
SP-Southern Plains
CP- Central Plains
NP- Northern Plains
IM- Intermountain Region

Fig. 1. Mean annual precipitation, in inches, in the 17 western states, 1931-1960, with approximate regions of dryland agriculture. (Adapted from "Summer Fallow in the Western United States" USDA-ARS Conser. Res. Rept. No. 17)

average precipitation increases from west to east in all Plains regions with the western sections receiving an average of about 305 mm.

Agricultural production in the Great Plains is subject to great annual fluctuations in precipitation and the occurance of high intensity summer rainfall events. These high intensity storms result in high runoff, thereby reducing the effectiveness of the precipitation.

Dryland farming in the intermountain region of the U.S. differs from that of the Great Plains in that it is not a large continuous farming area, but consists of smaller regions which receive about 50 percent or more of the annual precipitation from November to April. The Pacific Northwest region of eastern Washington, eastern Oregon, and adjacent northern Idaho is the largest and best known dryland area of the region, but for the purposes of this discussion other areas in these states, as well as Utah and western Colorado, are included as part of the intermountain region. The frost-free period ranges from 80 to 200 days (Leggett, et al. 1974). The principal difference between the areas is the form of the winter precipitation, either snow or rainfall, and the extremes between summer and winter temperatures. The Pacific Northeest region tends to have less climatic variability than the other regions.

PRACTICES FOR WATER CONSERVATION

Summer fallow

The practice most common to crop production in semiarid regions of the U.S. is summer fallow. This is the practice of leaving the land free from growing vegetation during a crop season. This practice requires tilling the land during the normal growing season to prevent water loss through weed growth. Several factors determine whether the practice of fallow will be beneficial; (a) the annual average precipitation should not be sufficient to wet the soil throughout the root zone, (b) the soil should be deep enough and have an adequate water holding capacity to retain the water made available for storage during the fallow period, and (c) the crop to be grown should have sufficient root development to utilize the stored water. In general, the 500 mm limitation previously discussed for summer rainfall areas is the boundary where fallow becomes feasible. However, the efficiency of fallow differs greatly due to the other factors involved.

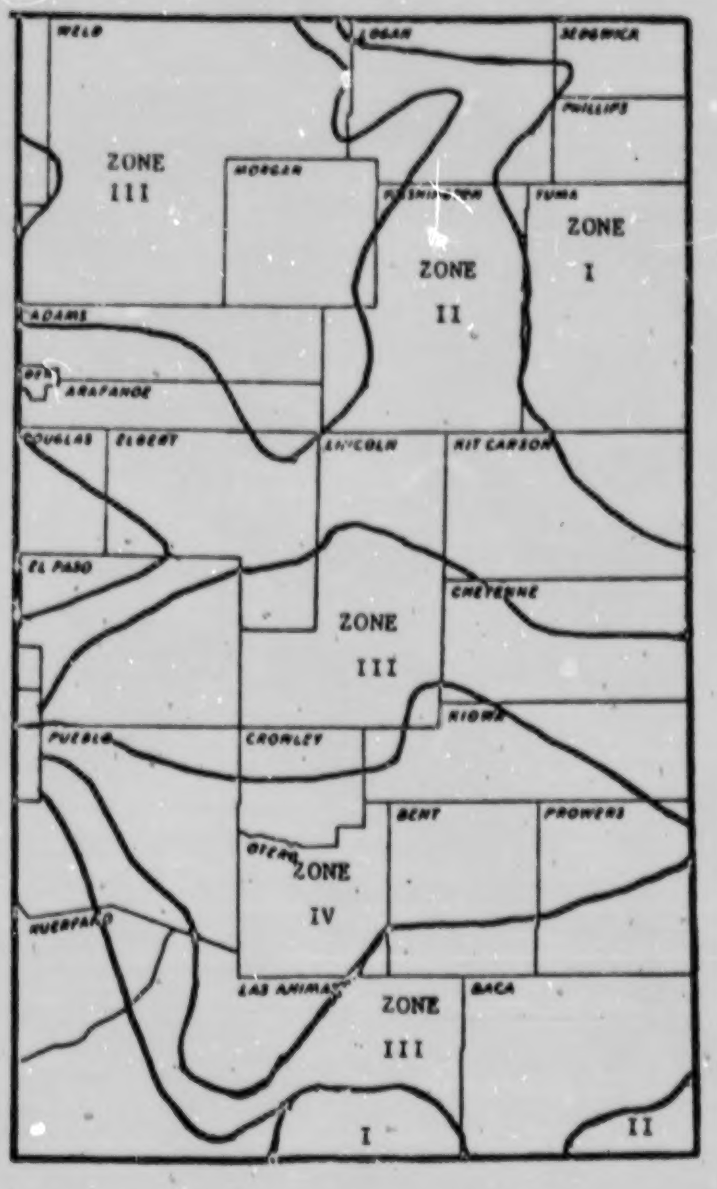
The purpose of summer fallow is to store soil water and accumulate nitrate nitrogen for the succeeding crop. The term is somewhat misleading in that the actual storage of water does not occur during the summer period. Summer fallow as practiced for the production of winter wheat encompasses a 14 to 15 month period starting with the harvest of one crop, usually in June or July, and continuing until planting during September of the next calendar year. Kuska and Mathews (1944) reported that with spring wheat at Colby, Kansas, the greatest water storage occured during the first fall and winter with lesser amounts the following spring and summer and still less during the second winter. Unpublished data from Colorado, and the data reported by Mathews and Brown (1938) show that significant amounts of water are stored during the summer period only when greater than average rainfall is received. Only an average of 1.45 cm was stored during the May to September period in Colorado, while in Kansas it was found that 10 cm of rainfall was required during the July to September period before any water was stored. Large losses of stored soil water can occur if weed control is poor during the summer tillage period, but usually evaporation accounts for most of the losses during this period. More water is stored during the first winter of the fallow season, primarily as a result of a crop being harvested the previous summer and less evaporation losses during the winter.

Fallow efficiency

Water storage efficiencies reported for the northern, central, and southern Great Plains reflect the effect of increased mean annual temperature on the efficiency of fallow in summer rainfall regions (Black, Siddoway and Brown 1974, Greb et al. 1974, Johnson et al. 1974). An average of 71.4 percent of the over-winter precipitation and 5.9 percent of the summer precipitation were stored during the fallow year in the Northern Great Plains. The average for the entire fallow period was 27.6 percent. This figure reflects the effect of annual distribution of precipitation with only about 25 percent of the precipitation being received during the period of greatest storage. Storage efficiency for the fallow period in the central Great Plains has been reported to be 20 to 25 percent (Greb et al. 1974). Higher efficiencies, due to improved practices on experimental plots have been reported to be about 35 percent (Greb, Smika, and Black 1967). Historical data compiled by B. W. Greb shows increased average yields in the central Great Plains since 1965. These increased yields are due, at least in part, to increased fallow efficiencies but the greatest average increases have occured in the higher rainfall areas. The water storage efficiency for the southern Great Plains has not been significantly improved since reported at about 16 percent by Mathews and Army in 1960.

Smika (1970) reports no crop failures with winter wheat after fallow at North Platte, Nebraska. However, the practice of fallowing the land does not insure the production of an economical crop every year in all parts of the Great Plains. Brengle and Greb (1963) reported crop failure with both continuous wheat and wheat after fallow in northeastern Colorado. The annual variability of precipitation and temperature is so great that it is possible to obtain high yields in given years without fallow and to have complete crop failures some years when the crop is planted after fallow. Army, Bond, and VanDoren (1959) reported that wheat yields in a wheat-fallow system at Bushland, Texas could be expected to be more than 672 kg/ha. 80 percent of the time. In the lower precipitation areas of eastern Colorado, 380 mm or less, the percentage of crop failures increases considerably above this, but in the higher precipitation area of northeastern Colorado with about the same precipitation as Bushland, 455 mm, the percentage of years in which crops exceed 672 kg/ha. is probably closer to 95 percent.

Figures 2 and 3 are included to illustrate the variability encountered in a relatively small portion of the central Great Plains. Figure 2 shows the precipitation zones of eastern Colorado (Brown et al. 1944). The precipitation varies from less than 330 mm to 483 mm. Figure 3 shows the planted and harvested acre yields and percent abandonment of winter wheat in the principal wheat producing counties of the area (Data compiled by B. W. Greb Research Soil Scientist, Central Great Plains Field Station, Akron, Colo.).


WELD
LOGAN
SEDGWICK
PHILLIPS
ZONE III
MORGAN
WASHINGTON
YUMA
ZONE I
ZONE II
ADAMS
ARAPAHOE
DOUGLAS
ELBERT
LINCOLN
KIT CARSON
EL PASO
CHEYENNE
ZONE III
KIOWA
PUEBLO
CROWLEY
BENT
PROWERS
OTERO
ZONE IV
HUERFANO
LAS ANIMAS
ZONE III
BACA
I
II

ZONE	EFFECTIVE RAINFALL
I	17-19 inches
II	15-17 inches
III	13-15 inches
IV	< 13 inches

Fig. 2. Precipitation zones in eastern Colorado (Colorado Agr. Exp. Sta Bul. 486)

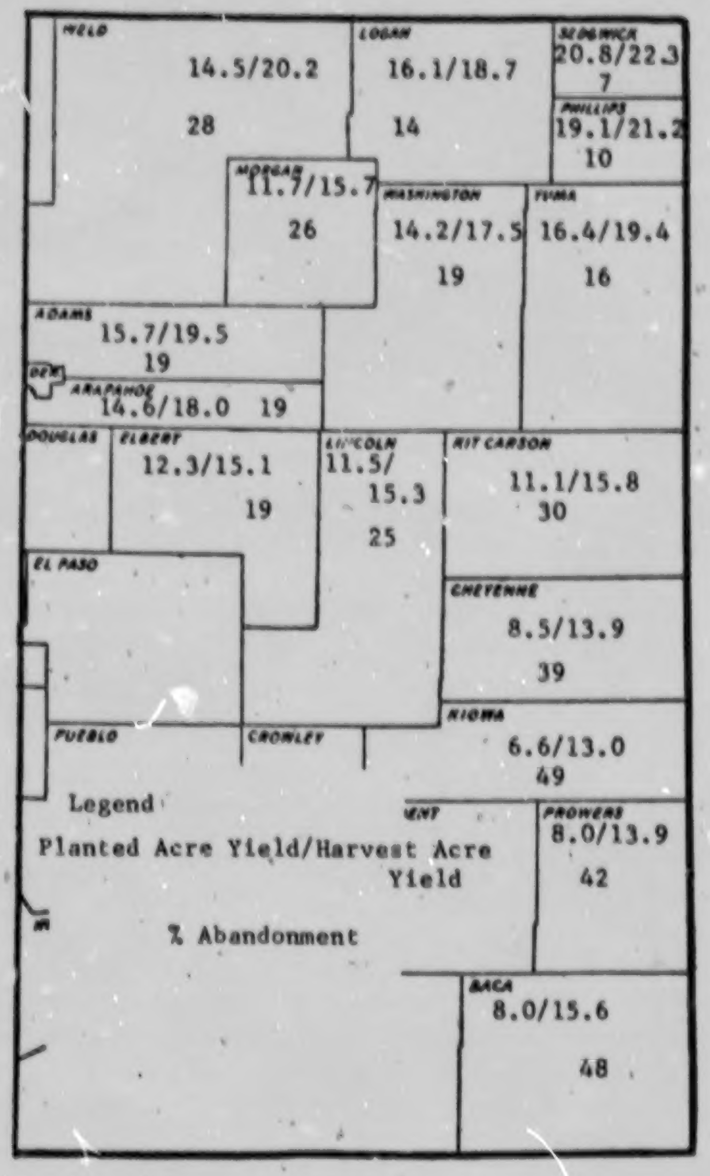

WELD
14.5/20.2
28
LOGAN
16.1/18.7
14
SEDGWICK
20.8/22.3
7
PHILLIPS
19.1/21.2
10
MORGAN
11.7/15.7
26
WASHINGTON
14.2/17.5
19
YUMA
16.4/19.4
16
ADAMS
15.7/19.5
19
DEN
ARAPAHOE
14.6/18.0 19
DOUGLAS
ELBERT
12.3/15.1
19
LINCOLN
11.5/
15.3
25
KIT CARSON
11.1/15.8
30
EL PASO
CHEYENNE
8.5/13.9
39
PUEBLO
CROWLEY
KIOWA
6.6/13.0
49
ENT
PROWERS
8.0/13.9
42
BACA
8.0/15.6
48
Legend
Planted Acre Yield/Harvest Acre Yield
% Abandonment

Fig. 3. Average yield per planted and harveste acre, and percent abandonment in eastern Colorado. 1939-1958.

These data are old, but although average yields have increased for each of the counties in recent years, the same relationships remain. Winter wheat production in the 330--381 mm precipitation zone is marginal, but it is more stable in this zone in the northern part of the state. Average yields are higher and percentage abandonment is lower. Differences in soils contribute to somewhat better conditions in the northern part of the state, but, largely, differences in evaporation and evapotranspiration rates affect the efficiency with which soil water is stored and utilized.

The increased water storage efficiency, and consequently, the greater stability of crop production in winter precipitation areas such as the Pacific Northeast is demonstrated in the data reported by Leggett, et al. (1974). Fifty to 75 percent of the precipitation received over the first winter of the fallow period is stored in the soil. During the summer period, when small amounts of precipitation are received, there is a net loss of stored water. When fallow is continued over the next winter, for the production of spring grains, additional water is stored in the soil although it is less than that stored the first winter. This storage occurs at locations where the annual average precipitation is 250 to 380 mm. At these precipitation levels in the summer rainfall areas, crop production becomes submarginal.

Soil type affects the fallow efficiency in that the soil must have adequate water holding capacity to benefit from the additional water provided during the fallow period. As a rule, soil that is light sandy loam or loamy sand texture throughout the profile does not provide an adequate reservoir to benefit as greatly from fallow as heavier textured soils.

Methods of summer fallow

The practice of summer fallow came about in the semiarid regions of the United States through necessity. Annual crop production was so unstable that early farmers sought ways to improve it and fallow was the best practice developed. Nearly all of the early fallow was accomplished with plows that turned the soil, thus burying the crop residue. This practice, generally referred to as clean tilled or black fallow, is practiced today to a greater extent than is desired. Clean tilled fallow leaves the soil surface exposed and susceptible to erosion. The early use of a dust mulch, which was relatively effective in retarding evaporation, was discarded principally due to the wind erosion hazard presented by the practice. This practice involved pulverizing the upper 5 cm of the soil, thereby breaking the capillary continuity of the soil and retarding water movement to the evaporating surface.

The practice of stubble mulch was developed primarily to reduce the erosion hazard encountered in the summer fallow program. Stubble mulching is effective in the control of both wind and water erosion. The practice requires undercutting crop residue with some type of subsurface implement, usually a V shaped sweep varying in width from 45 to 176 cm.

Data reported on water storage with stubble mulch has been variable and in most cases, the increases over black fallow have not been great. Theoretically, water storage should be increased with stubble mulch since surface runoff is reduced and evaporation should be decreased due to decreased radiation and wind velocities at the soil surface. Actually, the decrease in evaporation is principally a decrease in rate. If the evaporative demand remains high over a sufficient length of time, the total evaporation will amount to about the same as occurs from bare soil. The increased fallow efficiency reported for the central Great Plains is based on measurements with high rates of wheat straw applied to the soil surface (Greb, Smika, and Black 1967). These tests indicate that it is desirable to retain as much residue as possible on the soil surface to increase the available water supply.

Timeliness of tillage in the fallow period is extremely important if water losses from weed growth are to be prevented. Most locations in the Great Plains have reported that there is no advantage to fall tillage in the fallow system. Greb et al. (1974) reported increased storage at Akron, Colorado and North Platte, Nebraska with fall weed and volunteer grain control. Experiments at Springfield, Colorado have disclosed that fall tillage is of little value in this area (Unpublished data Colorado State University Experiment Station). Several investigators have found the first tillage operation in the spring to be the most important. It is necessary to obtain good control of weeds at this time in order to prevent large losses of water. Tillage in the fall of the fallow year is desirable in most areas receiving winter precipitation in the form of snow. Legget et al. (1974) report additional water storage in eastern Idaho by fall chiseling, and Brengle, Mann, and Schliebe (1970) found fall plowing necessary for the optimum production of dry fieldbeans (Phasolus vulgaris L.) in southwestern Colorado.

The type of implements used in the stubble mulch system depend primarily on two things. (a) the amount of stubble anchored in the soil at the first tillage operation, and (b) the amount of stubble desired at seeding. Many farmers prefer to have all residue turned under at planting time in order to have a clean seedbed, however, there are advantages to having at least 1200 to 1800 kg of straw per hectare left at planting. In areas where blowing snow can be trapped, a rough surface with residue is an advantage. In areas where wind erosion is a serious hazard, such as in all sections of the Great Plains, residue cover in the spring is advantageous to prevent wind erosion damage to the crop. Krall, Power, and Massee (1958) and Fenster (1961) have reported the effect of various implements on the destruction of residue.

The principal disadvantages to stubble mulch are: (a) weed control with stubble mulch may be less effective than with plowing under certain conditions, (b) operation of the tillage equipment is critical in that correct implement adjustment and speed of tillage are necesaary if tillage is to be satisfactory, and (c) seebed preparation and planting with surface stubble requires the correct type of implement and more care by the operator. Downy brome (Bromus tectorum) can become a serious problem with stubble mulch in most areas where wheat is produced. In western Colorado, this weed presents a serious problem when sub-tillage is used in the production of annually cropped wheat (Brengle and Greb 1963). Seedbed preparation with a rod weeder or skew treader is necessary for the most desirable results. The skew treader is most desirable where large amounts of straw remain at seeding. This implement is effective in knocking down and spreading straw.

Chemical control of weeds has been tried in most dryland areas of the United States with varying degrees of success. Swan, Oveson, and

Appleby (1974) provide a good literature review of chemical use in a fallow program in their recent publication. In general, the results of tests with chemicals have been contradictory. It is necessary to have sufficient available water for active plant growth for chemicals to be effective. Most of the reports of good weed control and minimal residual damage to subsequent crops have been from higher precipitation areas of the Great Plains and the Pacific Northwest. Some reports, such as that of Black and Power (1965), stress the necessity of mechanical tillage with the use of chemicals. Soil type and rainfall largely control the need for mechanical tillage and the residual damage to the following crop. The more common herbicides that have been used in chemical fallow are 2,4-D ((2,4-dichlorophenoxy) acetic acid), atrazine (2-chloro-4-(ethylamino)-6-(isopropylamino)-5-triazine), and amitrole (3-amino-5-triazol).

Winter wheat (Triticum aestivum L.) is the crop occupying the greatest acreage of land that has been fallowed. The 14-month period of fallow for this crop is the most efficient for most areas. Some areas of the northern Great Plains and the Intermountain Region find it profitable to fallow for the production of spring wheat. In the central and southern Great Plains, summer fallowing for spring planted crops is generally not economical.

Ridge terraces

Terraces have been used in dryland areas principally as water conservation structures. Ridge type terraces constructed on the contour have been used to retain water on the field. With these terraces, the water is confined to a relatively narrow strip immediately behind the ridge and does not provide any great benefit to the large area between ridges. Crop yields are usually reduced in the terrace channel during wet periods. The extent of damage depends on the length of time the crop is subjected to standing water and to the stage of growth of the crop. During periods when precipitation is deficient, the ridge is often too dry to produce good crops. Terraces of this type have not actually performed the function for which they were intended and their use has decreased. The need to farm fields with these terraces on the contour has probably had as much to do with their lack of acceptance as the poor water distribution which is an inherent characteristic of their design.

Level bench terraces

The conservation bench terrace was first initiated by A. W. Zingg at the Southwestern Great Plains Field Station at Bushland, Texas in 1955. This terrace is designed to catch runoff water and spread it over a leveled area that is to be intensively cropped. The basic idea is not new, but it had not been applied to modern agriculture as it is known today.

These terraces require leveling an area on the contour about 30 meters wide with a contributing area on sloping land above the bench to provide runoff. The contributing slope is farmed to some suitable crop, either an annually grown spring crop or possibly a fallow winter wheat rotation.

Mickelson (1966, 1968) did considerable work in evaluating these terraces and the ratio of level bench to contributing area most efficient for eastern Colorado conditions. He first reported a 3/1 ratio of contributing slope to bench width to give the best results but later reported a contributing area to bench ratio of 2/1 to be the more efficient. Haas, Willis, and Boatwright (1966) found that runoff from wheat or grass contributing area had minor effect on water storage and yields on bench terraces in the northern Great Plains with a ratio of contributing area to bench area of 1/1. They stated that the principal advantages of level bench terraces appear to be collecting snow, preventing runoff of snow melt and torrential rains, reducing erosion, and increasing crop yields through water conservation. In the central Great Plains, Mickelson reported that in a four-year period the average increase in water storage on the benches was about 5 cm. and annual sorghum production increased about 120 kg/ha.

There are several problems associated with the use of conservation bench terraces. The crop grown on the contributing area must be managed in such a way that runoff events will not present an erosion hazard and at the same time, especially in areas where snow collection is not adequate to supply significant amounts of water, provide some additional water to the bench area. The period of the year when runoff is received largely determines the crop to be grown. Failure to establish winter wheat on conservation bench terraces at Akron 2 out of 4 years restricts their effectiveness for this crop when grown annually. The yield of grain sorghum grown annually on benches receiving runoff was 448 kg/ha greater than biannual yields on fallow.

The collection of water on the bench area has presented some problems in that during light runoff events, distribution across the width of the terrace has been poor and during large runoff events, farming operations have been delayed or prevented and growing crops have been damaged.

Parallel bench terraces

The use of parallel level benches is also being studied by Mickelson (Personal Communication). This system is designed to transport water from a 913 hectare, grassed watershed by a diversion terrace to a waterway along the ends of each of 3 level benches, 0.7 hectare in size. Gates constructed in the waterway are used to measure runoff onto the bench or they are closed to allow runoff to enter the adjacent bench. In this study, one level bench does not receive runoff. The benches receiving runoff produced 393 kg/ha more dry matter than the level check and 1333 kg/ha more than the unleveled check.

Level pans

Leveled areas have been placed in a broad natural drainage at the central Great Plains Field Station at Akron, Colorado (Figure 4). These areas, referred to as level pans, ranging in size from less than one hectare to about 3.5 hectares, are designed to trap runoff from a watershed of about 200 ha. Standing water will collect in one pan to the desired height and then drain the excess water so that it may collect in the next pan. The runoff water in the drainageway may be diverted from the pans at times when excess water would be detrimental to farming operations or growing crops. The additional water collected in these pans permits annual crop production.

The amount of water collected in the pans depends on the number and type of runoff events and the location of the pan in relation to the other pans. The toal available water in the soil profile was 10 to 18 cm. greater on some pans than on corresponding check areas which were annually cropped (Mickelson, Cox, and Musick 1965). In 1966, Mickelson reported the data for a four-year period which showed improved water use efficiency from level

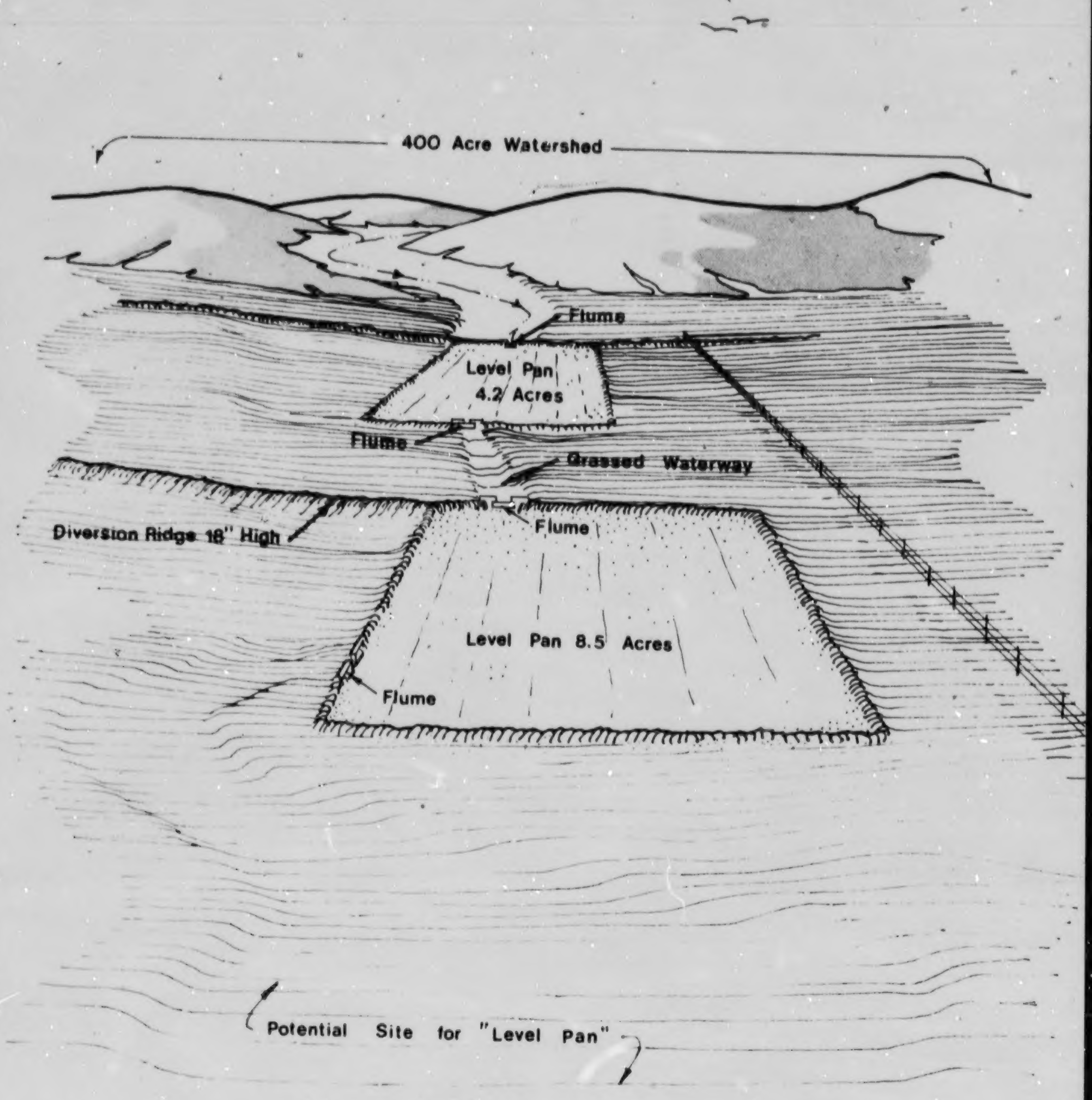

400 Acre Watershed
Flume
Level Pan 4.2 Acres
Flume
Grassed Waterway
Diversion Ridge 18" High
Flume
Level Pan 8.5 Acres
Flume
Potential Site for "Level Pan"

Fig. 4. Schematic representation of level pan system for intercepting, spreading, and storing runoff from a contributing watershed. (Mickelson 1966)

pans with an increase in yield of 115 to 278 kg of grain sorghum per additional inch of water. The value of these level pans in the Great Plains is probably in the production of supplemental feed where land is suitable for their installation.

Pitting

Pitting and ripping are practices that have been tried in the Great Plains to trap and hold water. Pitting is used principally on cultivated land and ripping on rangeland. Pitting is generally performed with some specially made implement that systematically digs out soil leaving pits in which water can collect. This is a practice which is accepted in some localities but has not gained wide acceptance throughout the dryland regions. It is difficult to conduct meaningful research on the practice of pitting and very little work has been done on it.

Strip cropping

Alternate strips of crop and fallow are used to some extent to control soil erosion. Strips used to control wind erosion are straight strips situated as nearly as possible at right angles to the prevailing wind. The width of these strips depends on soil texture in a given area. Strips on light textured, highly erosive soil should be narrower than strips on heavier soil types. There is no evidence that use of wind-strip cropping promotes better soil water storage or water utilization by plants. The acceptance of strip cropping for wind erosion control has not been great by farmers, although the wind erosion hazard is quite high.

The use of contour strip cropping is even more limited than straight strip cropping in dryland areas since it is a practice designed primarily to reduce water erosion. Water erosion is probably a more serious problem in the areas receiving winter precipitation and the topography of many of these areas is too irregular for contour strips to be practical.

Wind breaks

Windbreaks or field shelter belts have been used to varying degrees in the Great Plains. Shelter belts may consist of one or more rows of trees, and they are designed principally to reduce wind velocity and prevent soil erosion. However, in areas that receive substantial amounts of snow, they may have a favorable effect on soil water storage. In Canada, a net increase in wheat yields on only .84 kg/ha was reported (Staple and Lehane 1955). The net increase was due to higher water storage, and yield adjacent to the shelter belt.

A report from Russia claimed that a field protected by a shelter belt had increased water 30 to 40 percent in the spring resulting in increased crop yields of 150 to 200 percent (Budyko and Pogosian 1959). At Akron, Colorado, soil water is decreased adjacent to old, well established windbreaks since snow accumulation is not adequate to supply all of the water required by the trees. Broadleaf trees are the heaviest users of water and can decrease the available water up to a distance of 20 meters from the shelter belt.

Annual vegetative barriers to trap snow have been investigated at Akron, Colorado and Sidney, Montana. These barriers are double rows of grain sorghum (Sorghum vulgare Pers.) or tall wheatgrass (Agropyron elongatum) spaced at 10 to 20 meters. Black et al. (1974) report that during the over-winter period at Sidney, snow trapped within double barriers of tall wheatgrass increased soil-water recharge enough to equal 14 to 21 months of fallow.

CROPS AND CROPPING SYSTEMS

Crop adaptability

Hard red wheat has traditionally been the principal crop of the temperate semiarid regions. The milling and baking quality of hard red winter and hard red spring wheats grown under dryland conditons is generally superior to that of similar wheat grown under higher precipitation.

Hard red winter wheat has been the principal crop of the southern high Plains and the central Plains areas since the early 1940's. Hard red spring wheat is the crop grown on the largest acreage in the northern Great Plains but the production of winter wheat has increased greatly over the past few years, particularly in Montana. The development of more winter-hardy varieties and improved management practices have been responsible for the

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increase in winter wheat in this region. Crops of less importance in the northern plains are barley (Hordeum vulgare L.), durum wheat (Triticum durum Desf), oats (Avena sativa L.), and corn (Zea mays L.). Grain and forage sorghums are the principal secondary crops in the southern and central Great Plains. Relatively small acreages of corn are grown in the central Great Plains, generally on sandier soils. Proso millet, (Panicum milaceum) and foxtail millet (Setaria italica) are also grown on limited acreages in N.E. Colorado (Hinze 1972). The proso millets are grown for grain and are used in mixed livestock feed. Foxtail millet is grown principally for hay. Grain yield of proso averaged 1177 kg/ha for the 1965-69 period N.E. Colorado.

Wheat is also the principal crop of most of the dryland areas of the intermountain region. In the Pacific Northwest, winter and spring wheat and winter and spring barley, and peas are the crops primarily grown. In the San Juan Basin of southwestern Colorado and southeastern Utah, dry fieldbeans is the principal crop, with winter wheat being the secondary crop.

Cropping systems

Alternate wheat and fallow is the cropping system utilized on the greatest land area in the dryland reigons of the United States. Fallow is necessary for the economical production of wheat in most areas of the Great Plains that receive less than 500 mm of annual precipitation. Annually cropped wheat in years of high precipitation will produce good yields and wheat after fallow can fail in years of deficient precipitation. The practice of alternate wheat-fallow requires twice as much land as needed for annually grown wheat since there must be one hectare of fallow for each one planted to wheat. However, the yield from wheat after fallow does not need to be twice that of annually cropped wheat to be economical. Planting wheat after fallow stabilizes wheat production by eliminating some crop failures and increasing the number of economical yields produced over a period of years. Fallow also results in better quality grain as measured by the test weight.

Some fallow is used for the production of grain sorghum in the southern and central Great Plains. This practice is not extensive due to (a) less economic importance of sorghum, (b) to the extreme wind erosion hazard resulting from the longer fallow period, and (c) more inefficient soil water storage over the longer fallow period. The wind erosion hazard is greatest during the spring months and fallowing for sorghum dictates that the land be left without a growing crop over two spring periods, and it is almost impossible to maintain an adequate residue cover over the second winter and spring. A common practice is to use wheat and sorghum in a wheat-sorghum-fallow sequence. The fallow period is shorter in this sequence than in the wheat-fallow system but this does not appear to seriously affect the yield of wheat in areas receiving 400 mm or more precipitation. Wheat-millet-fallow rotation shows some promise in N.E. Colorado (Hinze. Personal Communication).

Fallow is used with both wheat and barley in the northern plains. Fallow is generally not used with corn or oats.

The cropping systems used in the various areas of the intermountain region depend largely on annual precipitation (Leggett et al. 1974). Alternate fallow is generally used with winter or spring wheat and winter or spring barley in the Northwest region where annual precipitation is less than 330 mm. The 330 to 410 mm precipitation areas of this region may or may not use fallow with crops. In the regions receiving greater than 410 mm of annual precipitation, annual cropping is practiced with wheat, barley, and peas. Occasionally, these crops are used in rotation with alfalfa, (Medicago sativa L.) or fallow.

In southwestern Colorado, dry fieldbeans are annually cropped in areas of 330 to 430 mm annual precipitation. Some fallow is used for winter wheat production in the area but where wheat is produced, the more common cropping system is to follow beans with wheat. Beans may be grown any number of years before wheat is planted. Wheat following beans is planted later than desirable, but yields are not seriously decreased by this practice. Dry fieldbeans do not deplete the soil water below a depth of 60 cm., thereby leaving a reservoir of soil water for the following crop. Although over-winter water storage is good in this area, the production of annually cropped wheat is less stable than that of wheat following beans.

In general, the cropping sequences used in dryland areas of the continental United States are designed to utilize the existing water in the most efficient manner while providing reasonable protection to the soil. The systems using two years of crops in a sequence with fallow, favor the wheat crop while utilizing the water stored over the winter following wheat harvest for the spring planted crop. These systems also provide two cash crops in three years compared to the one crop every other year produced in a single crop-fallow sequence. The systems utilizing two crops are well adapted to strip cropping and can increase the protection needed to reduce wind erosion.

Fertilizer use

The use of commercial fertilizers with dryland crops has been investigated in most semiarid regions of the United States (Brengle and Greb 1963, Eck and Stewart 1959, Lowry et al. 1956, Wash. Agr. Ex. Ser. 1959). Soils tests for nutrient levels are limited in their value in the Great Plains area, since the correlation between soil test value and response to fertilizer is dependent upon adequate soil moisture.

Nitrogen is the fertilizer element found to be the most beneficial in most areas. Crop responses to phosphorus have been reported in western Oklahoma and North Dakota (Eck and Stewart 1959, Reimer and Olson 1954).

In Colorado, responses to nitrogen fertilizer occurs more frequently on light textured, loamy sand, and sandy loam soils. Fertilizer use with wheat grown on medium or heavy textured soils has resulted in increased yields only with annually cropped wheat or wheat grown on severely eroded areas. Nitrogen build-up occurs during the fallow period and is apparently adequate in these soils to supply the nitrogen needed by the crop at the yield levels being produced. About 34 kg/ha is the optimum rate of nitrogen for wheat grown on the sandy soils in Colorado.

Other areas in the Great Plains have reported optimum nitrogen applications to be about 45 kg/ha (Eck and Stewart 1954, Lowry et al. 1956). Regions with winter precipitation use higher rates of nitrogen in precipitation zones comparable to those in the plains area (Peterson 1952, Wash. Agr. Ex. Ser. 1959). In eastern Washington, nitrogen rates up to 90 kh/ha are recommended (Wash. Agr. Ex. Ser. 1959).

Nitrogen applications on winter wheat will often have a greater effect on protein content of the grain than on yield. Under poor water conditions, the higher protein is the result of shriveled grain.

Commercial fertilizer is not used as extensively on crops of less economic importance. Favorable responses to nitrogen have been obtained with grain sorghum in Colorado but the probability of increasing yield is not as good as with wheat. In the regions of the Great Plains where grain sorghum production is more favorable, the nitrogen rates used are about the same as those for wheat.

SUMMARY

The practices used in dryland agriculture are designed to conserve or concentrate adequate water for stable crop production. Summer fallow, utilizing good stubble mulch practices, is the best known method of water conservation in temperate dryland areas where wheat is produced on large acreages using large farming equipment. Where soil erosion is a problem, it is fortunate that this practice is also the best soil conservation practice.

In areas where fallow is not adaptable due to low annual precipitation, unfavorable annual distribution of precipitation or high potential evaporation, water concentrating methods offer some promise of increase crop production. These methods that involve land farming to provide areas suitable for cropping are dependent on collecting runoff and must be adapted to each individual situation. Water harvesting strictly for crop production may be necessary for some areas, particularily in regions adapted to farming smaller land areas. These systems limit the crop to be grown to some extent since usually the period of plant growth must coincide with the period when runoff water is available. Considerable research is needed in these areas on water concentrating systems for crop production.

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LITERATURE CITED

Army, T. J., J. J. Bond, and C. E. VanDoren. 1959. Precipitation yield relationships in dryland wheat production on medium to fine textured soils of the Southern Great Plains. Agron. Jour. 51:721-724.

Black, A. L. and J. F. Power. 1965. Effect of chemical and mechanical fallow on moisture storage, wheat yields, and soil erodibility. Soil Sci. Soc. Amer. Proc. 29:465-468.

Black, A. L., F. H. Siddoway, and P. L. Brown. 1974. Summer fallow in the Northern Great Plains (winter wheat). Chapter 3. Summer Fallow in the Western United States USDA-ARS Conservation Research Report No. 17.

Brengle, K. G. and B. W. Greb. 1963. Comparison of continuous wheat and wheat after fallow in Colorado. CSU Exp. Sta. Bul. 518-S.

Brengle, K. G. and B. W. Greb. 1963. The use of commercial fertilizers with dryland crops in Colorado. CSU Exp. Sta. Bul. 516-s.

Brengle, K. G., H. O. Mann, and K. A. Schliebe. 1970. Crop yields and water use with dryland crops in Colorado. CSU Exp. Sta. Tech. Bul. 112.

Brown, L. A., et al. 1944. Land types in eastern Colorado. Colorado Agr. Exp. Sta. Bul. 486.

Budyko, M. T. and K. H. Pogosian. 1959. Modification of climate in the surface layer of the atmosphere with the amelioration of drought areas. English translation in Weekly Weather and Crop Bulletin, U.S. Dept. of Comm. November 30, 1959.

Eck, H. V. and B. A. Stewart. 1954. Wheat fertilization studies in western Oklahoma. Okla. Agr. Exp. Sta. Bul. B-432.

Eck, H. V. and B. A. Stewart. 1959. Response of winter wheat to phosphate as affected by soil and climatic factors. Agron. Jour. 51:193-195.

Fenster, C. R. 1961. University of Nebraska Extension Service. Agronomy Tips No. 112.

Greb, B. W., R. H. Mickelson, and G. O. Hinze. 1965. Conservation research at the Central Great Plains Field Station. Central Great Plains Field Station, Akron, Colorado. USDA-ARS.

Greb, B. W., D. E. Smika, and A. L. Black. 1967. Effect of straw mulch rates on soil water storage during summer fallow in the Great Plains. Soil Sci. Soc. Amer. Proc. 31:556-559.

Greb, B. W., D. E. Smika, N. P. Woodruff, and C. J. Whitfield. 1974. Summer fallow in the Central Great Plains. Chapter 4. Summer Fallow in the Western United States. USDA-ARS Conservation Research Report No. 17.

Haas, H. J., W. O. Willis, and G. O. Boatwright. 1966. Moisture storage and spring wheat yields on level-bench terraces as influenced by contributing area, cover, and evaporation control. Agron. Jour. 58:297-299.

Hinze, G. O. 1972. Millets in Colorado. CSU Exp. Sta. Bul. 553-S

Hinze, G. O. Personal Communication. Agronomist, Central Great Plains Field Station. Akron, Colorado.

Johnson, W. C., C. E. VanDoren, and Eall Burnett. 1974. Summer fallow in the Southern Great Plains. Chapter 5. Summer fallow in the Western United States. USDA-ARS Conservation Research Report No. 17.

Kroll, J. L., J. F. Power, and T. W. Massee. 1958. Summer fallow methods related to erosion and wheat production. Montana Agr. Exp. Sta. Bul. 540.

Kuska, J. B. and O. R. Mathews. 1944. Dryland crop rotations and tillage experiments at the Colby (Kansas) Branch Exp. Sta. USDA Circ. No. 979.

Leggett, G. E., R. E. Ramig, L. C. Johnson, and T. W. Massee. 1974. Summer fallow in the Northwest. Chapter 6. Summer fallow in the Western United States. USDA-ARS Conservation Research Report No. 17.

Lowry, G. W. et al. 1956. Commercial fertilizer results with winter wheat and rye. Neb. Agr. Exp. Sta. Outstate Testing Circ. 53.

Mathews, O. R. and L. R. Brown. 1938. Winter wheat and sorghym production in the Southern Great Plains under limited rainfall. USDA Circ. 477.

Mathews, O. R. and T. J. Army. 1960. Moisture storage on fallowed wheatland in the Great Plains. Soil Sci. Soc. Amer. Proc. 24:414-418.

Mickelson, R. H., M. B. Cox, and J. Musick. 1965. Runoff water spreading on leveled crop land. Jour. Soil and Water Cons. 20:57-60.

Mickelson, R. H. 1966. Level pan system for spreading and storing watershed runoff. Soil Sci. Soc. Amer. Proc. 30:388-392.

Mickelson, R. H. 1968. Conservation bench terraces in eastern Colorado. Trans, ASAE 11:389-392.

Mickelson, R. H. Personal Communication. Agricultural Engineer, Central Great Plains Field Station. Akron, Colorado.

Peterson, H. B. 1952. Effect of nitrogen fertilizer on yield and protein content of winter wheat in Utah. Utah Agr. Exp. Sta. Bul. 353.

Reimer, J. M. and H. M. Olson. 1954. Phosphate and nitrogen fertilizer trials on the Williston Substation. N. Dak. Exp. Sta. Bimonthly Bul. 16:146-149.

Smika, D. E. 1970. Summer fallow for dryland wheat in the semiarid Great Plains. Agron. Jour. 62:15-17.

Staple, W. J. and J. J. Lehane. 1955. The influence of field shelter belts on wind velocity, evaporation, soil moisture, and crop yield. Canadian Jour. Agri. Sci. 35:440-453.

Swan, D. G., M. M. Oveson, and A. P. Appleby. 1974. Chemical and cultural methods for Downy Brome Control and yield of winter wheat. Agron. Jour. 66(6):793-795.

Washington Agr. Extension Service. 1959. Effect of soil fertility and soil moisture on yield of wheat in eastern Washington. Wash. Res. Prog. Rept. No. 3-Agronomy.

RUNOFF AGRICULTURE: EFFICIENT USE OF RAINFALL

Martin M. Fogel[1]

INTRODUCTION

The spreading of water collected from catchments onto agricultural land for crop production is generally considered to be runoff agriculture. This type of agriculture was developed nearly 4000 years ago in the middle East to permit crops to be grown on lands receiving as little as 100 mm average annual rainfall. The water harvesting phase, sometimes called runoff inducement, will be discussed in later presentations. This discussion is concerned with the use of water generated by water harvesting systems for the production of crops including forage.

Planning for the use of runoff agriculture requires the consideration of two essentials. First, surface runoff water must be available in adequate timing and quantity for crop production. This means that the topography, geology, soil, vegetation and climate must combine each year to give at least a few sudden flows large enough to be useful but not too large to be damaging. The second essential is that the land on which the runoff water is used is suitable for crop production and is conveniently located to the runoff area.

The type of farming practiced must make the best use of the water. In general, perennial crops with deep root systems adapt better to runoff agriculture, because they can use runoff water stored deep in the soil safe from evaporation.

There are several variations to runoff agriculture. However, they all contain (1) a water supply produced by a runoff area, (2) a waterspreading site which consists of the cultivated area or the area on which forage is grown, and (3) a water distribution system.

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THE WATER SUPPLY

The water supply for runoff agriculture will generally come from a stream channel which is dry most of the time but which flows for short periods following heavy rains or snow melt. The first job of the planner is to determine whether the watershed area above the spreading site will furnish an adequate water supply. A rate of flow large enough for satisfactory spreading but not so large as to be unmanageable is necessary and a long period of flow is desirable.

The planner needs information on two points to decide on the sufficiency of the water supply: (1) the rate of peak flow per second; (2) the total volume available in a period of stream flow which will occur often enough to justify building the system.

Watershed characteristics that influence runoff

Watershed conditions are seldom uniform. They include a great variety of slopes, soils, vegetation, stream patterns and other variables which affect runoff. Examine the watershed with the following points in mind:

(1) Topography. Observe the slopes and exposed rock formations. These may be very important. If the rock layers or strata are tipped or inclined into the drainage area, conditions should be favorable for good runoff. If the reverse is true, runoff may be very low. On the other hand, a level bedded formation may provide an excellent site.

Note which slopes have the most vegetation. In dry regions, vegetation and water supply are closely interrelated. Where there is more vegetation, there is more soil moisture. Rainfall usually increases with elevation above the surrounding country. The higher the drainage area, the better are the chances for abundant runoff. Great differences in rainfall may occur within a few miles. Other things being equal, northern slopes usually yield the most water. If the stream gradients are steep, the streams may carry a large amount of bed load or heavy material ranging from quite fine particles to coarse gravel and boulders which roll or slide along the stream bottom during periods of flow.

Close observations of the small rills or depressions will indicate whether they carry water frequently. If flows are frequent, the channels will be swept clean excepting for drift material which is plainly water deposited. As a rule, the steeper the slope, the greater the runoff.

If the drainage area consists of many small, narrow valleys with steep slopes at right angles to the streams, the runoff will probably be rapid and total time of runoff short. With broad, flat valleys, the period of runoff will be much longer. The stream grades themselves will also affect period of runoff and peak flows. A long narrow drainage will have a longer runoff period and a lower peak than one which is wide and relatively short.

(2) Rainfall. Study all available rainfall records that may be representative of the drainage area. The distribution of the rainfall not only by months but by days is very important. The frequency of maximum intensity storms is also important. Runoff is usually produced by heavy rains falling in a short period of time. For example, if the average annual precipitation is 8 inches, and half of it usually occurs in June and July, it is desirable to know whether there are 15 days with rain during this period or only 5 in the average year.

(3) Soils. The soils of the runoff area should be carefully examined. Most clay soils absorb water slowly. Shallow soils over clay or impervious rock yield high runoff after the permeable layers become filled with water. Deep sandy soils and soils with good structure will absorb water rapidly and release it slowly. Sandy or silty soils are likely to be erodible, especially on steep slopes. Sometimes soils can be examined in the slides of gullies or cut banks.

(4) Vegetation. Vegetation is an important factor affecting water yield and type of stream flow. Watersheds with a heavy cover of grass, shrubs, or trees seldom produce sudden heavy runoff. Vegetation aids most soils to behave as a sponge in taking up moisture as it falls and releasing it slowly. This condition is favorable for sustained stream flow.

Vegetation is the most desirable medium of erosion control. Runoff from a drainage area with good vegetal cover will not carry too much sediment to burden the distribution system. If the drainage area vegetation is mostly grass, the situation is ideal, and improving the grass cover will not greatly reduce the water yield. Runoff from vegetated drainage areas may carry considerable drift of grass blades, leaves, twigs, and sticks which may be a nuisance in the distribution system but are to be preferred to large volumes of sediment.

(5) Available runoff records. Runoff records, when available, are the best source of information on water supply, particularly records which are continuous for a 20-year period or longer. The records from gaging stations on reservoirs and streams are valuable, the former more so than the latter. Here again the records are not likely to be reliable unless they cover a period of at least 20 years. Often gaging stations are so far removed from the drainage area that considerable care must be exercised in using the records. However, if conditions are reasonably similar, records from drainage areas 50 to 100 miles away may be useful.

Computing peak runoff by slope-area method

When runoff measurements are lacking, the slope-area formula is commonly used to compute peak discharge. The computation is based on water marks and drift lines left by high flows observed at several points. Sufficient high-water marks must be located along a reasonably straight, smooth portion of the stream channel to permit determination of the water surface slope at the time of the peak. Cross sections of the channel are

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then determined, usually by leveling. With an estimate of the channel roughness, the peak rate of flow is computed by either the Chezy or the Manning formula.

The volume of flow is difficult to estimate by this procedure as the duration of flow is not known. If flow durations can be estimated from available runoff data, a simple triangular hydrograph can be used to estimate volume of flow.

THE WATERSPREADING SITE

As stated earlier, the basic requirements for runoff agriculture are (1) a watershed that provides enough water to mature a crop and (2) a site suitable for crop production. Numerous favorable and adverse factors must be weighed against each other to determine whether a site is feasible, or to compare one site with another. An evaluation of these factors is also needed to determine the design of the distribution system. Some of the principal factors are discussed in the sections that follow.

Water supply factors to consider

Both volume and frequency of flow are important. While one flow per year may put sufficient moisture into the soil to produce a satisfactory crop, frequent floodings will naturally produce more yield. A small volume (especially if combined with infrequent flow) may not be worth the cost of diversion. A large volume may be too difficult to handle or too much for the size of the available spreading area. In this case, provision must be made to bypass the excess water.

The proper depth of water on the crop-growing area or rate of water application is also an important factor in planning the system. The decision will depend on the water supply, the infiltration and penetration characteristics of the soil, the tolerance of the plants to inundation and the normal season of available water.

For agricultural crop production, the distribution of rainfall events throughout the growing season is crucial to a successful harvest, particularly for the shallow-rooted crops. These crops require water more frequently than those having deep roots. The depth of application per runoff event can be balanced against the relative sizes of the runoff-producing and the crop-growing area. There is no alternative, however, to a scarcity of rainfall events.

For forage production, where surface and internal drainage on the spreading area are good and the water supply abundant, applications up to 300 mm in depth over the area are not too much, if a flow can be expected only once or twice during the growing season. If water is scarce and the area suitable for spreading is greater than the water supply (as is frequently the case), the application of 75 to 150 mm when available may produce more feed than heavier applications on a smaller area.

In connection with water supply, water quality is a factor that must be considered. If the water contains excessive amounts of dissolved solids, it may be unfit for spreading, and in a few years may ruin the soil on the spreading area. If the water supply is suspected of containing harmful salts, analyses should be made to determine if the quantity exceeds allowable tolerances.

Sedimentation factors to consider

Frequent and heavy deposits of sediment may interfere with the effective operation of the system. Such deposits will retard plant growth and may kill the younger plants. Even if the sediment is not excessive in amount, it may be made up of fine materials that will clog the soil pores on the cultivated area and in time reduce the water intake.

If the water coming to the proposed crop-growing site is on a steep gradient and flowing at high velocity, it may be carrying a large quantity of sediment. Most of this load will be dropped when the velocity is checked. Such a quick and heavy deposit of sediment in one place is a distinct disadvantage and must be avoided.

If sediment of high silt content is deposited slowly, it may be beneficial rather than harmful. The spreading water tends to deposit the sediments in a gently sloping plane which fills the low spots and small gullies and other irregularities. Silt deposited in such a manner actually improves the site for spreading purposes. The silt also adds to the soil depth and thus, generally improves growing conditions.

Unlike most types of sediment basins, a waterspreading system can function indefinitely without the loss of expensive storage capacity. As sediment accumulates, the height of the dikes can be increased and the storage capacity restored and enlarged. Rapid and heavy sediment accumulation, however, is usually indicative of serious soil erosion conditions in the drainage area upstream, and no time should be lost in applying corrective measures.

Site factors to consider

The ideal site on which to spread runoff water for crop production is a broad, smooth gently sloping plain whose soil is a deep fertile loam.

Runoff agriculture requires a deep soil that can store water between rains. It works best for deep-rooted crops such as trees and shrubs, which can tap stored water and depend less on frequent rainfall. In contrast, annual crops need rain at the beginning of the growing season and usually at intervals thereafter. The method is enhanced by plant varieties able to withstand intermittently wet and dry soil.

Environmental prerequisites include:

1. A minimum mean precipitation of 80 mm per rainy season if the rainy season coincides with the cold period of the year, more if it occurs during summer when evaporation is greater.
2. Soils in the crop-growing areas with high water-storing capacity.
3. Not more than 2 to 3 percent salinity in the cultivated soil.
4. A minimum of 1.5 m of soil depth in the cultivated area (unless water-storage facilities are available).

THE WATER DISTRIBUTION SYSTEM

Several runoff water distribution systems exist from simple terraces to complex diversions. The selection of a particular one will depend on the site factors encountered and on the crops to be irrigated with the harvested water. Usually range and pasture lands use a system in which water is diverted from a natural course onto the land by a system of diversion dams and spreader dikes. Other crops, such as fruits, barley, sorghum and millet, can use a similar waterspreading system or a technique known as desert-strip farming.

Waterspreading

In arid regions, the limited rainfall usually falls during short, intense storms. The water swiftly drains away into washes and gullies and is lost to the region. Sometimes floods occur often to areas untouched by the storm. Waterspreading is a practice of deliberately diverting the floodwaters from their natural courses and spreading them over adjacent floodplains or detaining them on valley floors. The wet floodplains or valley floors are then used to grow forage or cultivated crops (Figures 1 and 2).

The simplest waterspreading system is a small earth dam that may be less than one meter high and five meters long across a minor water course. If the land slopes away from such streams on either side, a number of these simple structures may spread water on a considerable area. This type of structure, but with slightly larger dams, may be effective on areas where the water diverted at any one point reaches 0.5 m^3/s. The next step or refinement is the conveyance dikes or ditches which transport the water from the diversion point on a natural water course to the crop growing areas. This may be some distance, up to several kilometers, in which case the dikes are actually ditches or canals. They can be built with earth taken from above or below the dike alinement. If the ground on which they are constructed has little slope, a strip up to 150 meters wide above the dike will be covered with water and irrigated whenever the system is in operation.

Spreading dikes are often found at the end of a conveyance dike. These dikes are usually a continuation of the conveyance dike with outlets for water. At appropriate intervals, part of the water is turned onto the land below the dike by means of outlets through the dike. For fairly clear water, outlets should be at the bottom of the flow channel at an elevation that will permit the water to come through the dike at the same elevation as the land on the lower side, thereby reducing erosion.

Waterspreading systems need a careful design and engineering layout to withstand floodwaters. While potential sites are found on many arid and

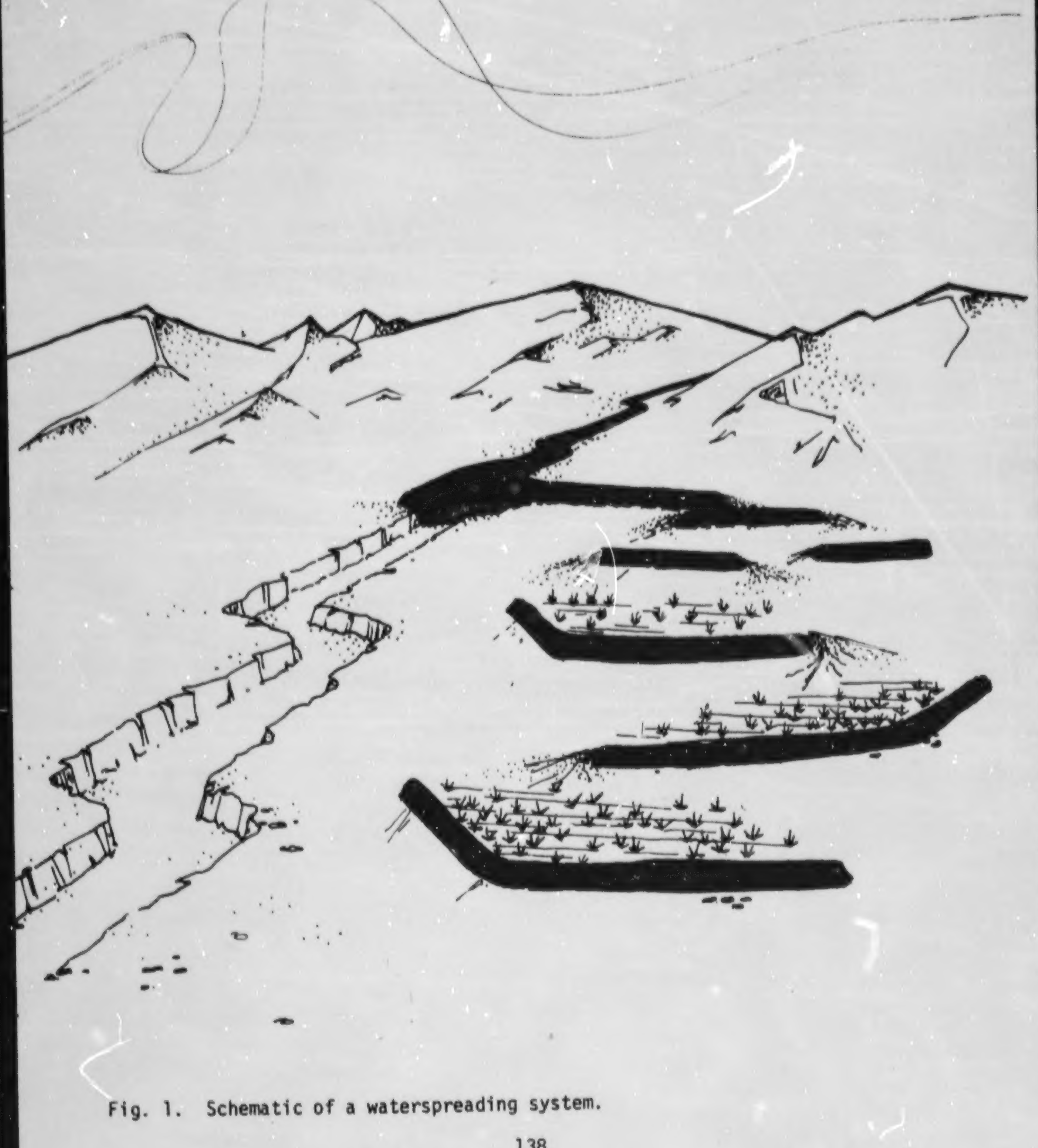


Fig. 1. Schematic of a waterspreading system.

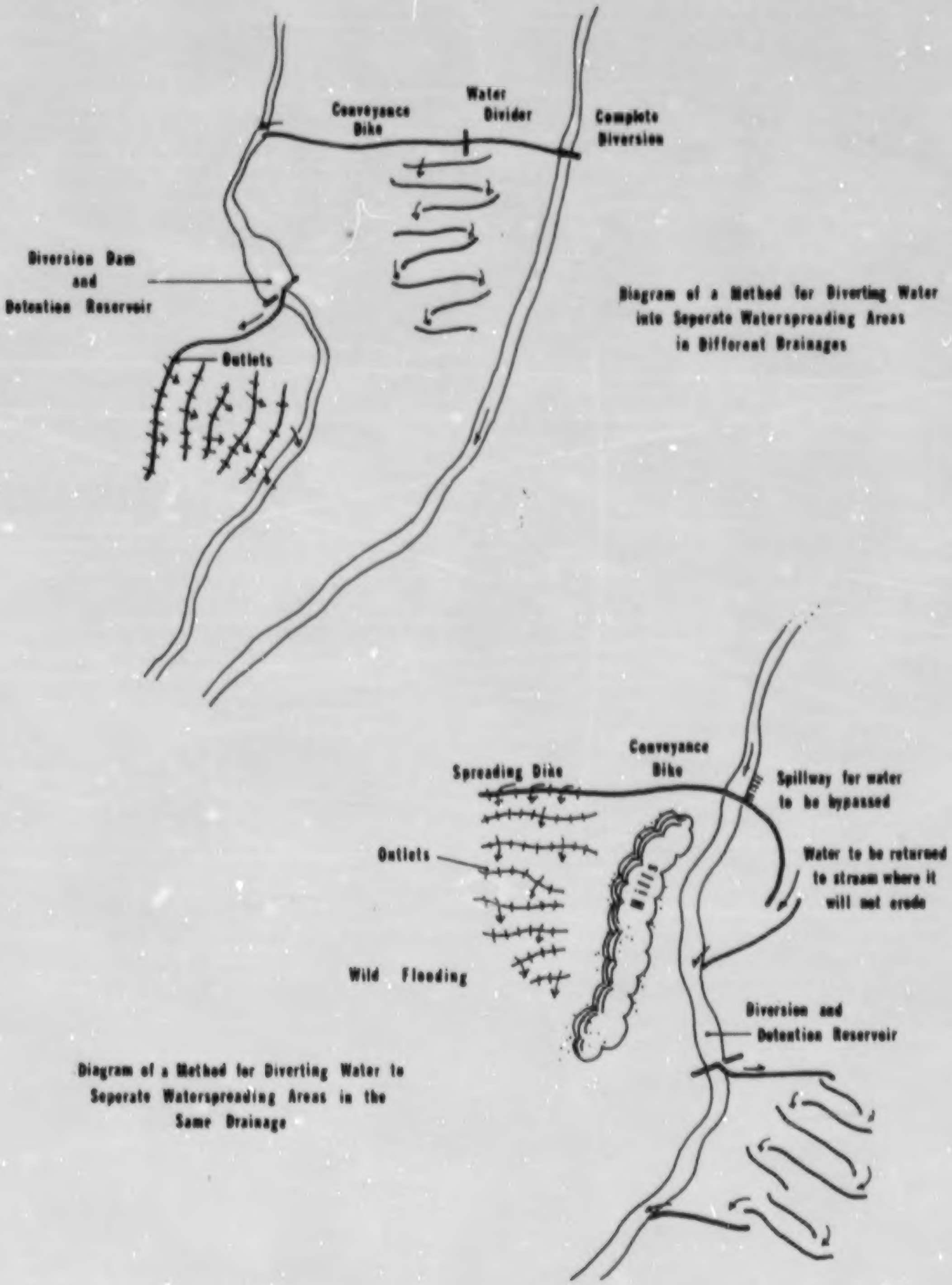

Conveyance
Dike
Water
Divider
Complete
Diversion
Diversion Dam
and
Detention Reservoir
Outlets
Diagram of a Method for Diverting Water
into Seperate Waterspreading Areas
in Different Drainages
Spreading Dike
Conveyance
Dike
Spillway for water
to be bypassed
Outlets
Hills
Water to be returned
to stream where it
will not erode
Wild Flooding
Diversion and
Detention Reservoir
Diagram of a Method for Diverting Water to
Seperate Waterspreading Areas in the
Same Drainage

Fig. 2. Possibilities for various types of structures used in waterspreading systems are illustrated.

semiarid ranges, they must be selected with full consideration for topography, soil type, and vegetation.

Desert strip farming

In arid and semiarid regions, although only a very small percentage of the rainfall reaches major stream channels, considerable runoff occurs on the gently sloping upland watershed areas. Desert strip farming makes use of this water by employing a series of terraces that shed water onto a neighboring strip of productive soil. They are often tiered up a hillslope, but on level terrain, an artificial slope for the catchment can be made by mounding the soil between the strips. The watershed section can be left in a natural state, cleared of vegetation, planted with range grasses or treated by some water-harvesting technique to induce runoff. (Figures 3 and 4)

IMPROVEMENT AND MAINTENANCE

The discussion that follows pertains mainly to the operation, improvement, and maintenance of waterspreading systems for forage production. The principles, however, are similar for using this method on other crops and for other methods of runoff agriculture.

Common design defects

It is difficult to design a waterspreading system which is free of flaws when first constructed. The flow of water is seldom the same in any two storms. Nevertheless, the system must handle these variable flows by one automatic plan. Incomplete and inaccurate basic data are frequently a further handicap.

Usually the first flow of water through the system will reveal the flaws in design. If the designer can be on hand to watch the water flow through the system, he will be able to recognize the defects of his plan much more quickly than if he has to study the effects of the flow after it has passed by. Following are some of the effects that may appear after the system receives a flow of water:

1. Too great a concentration of water hitting certain sections of a dike with too high velocity. This may cause the water to overtop

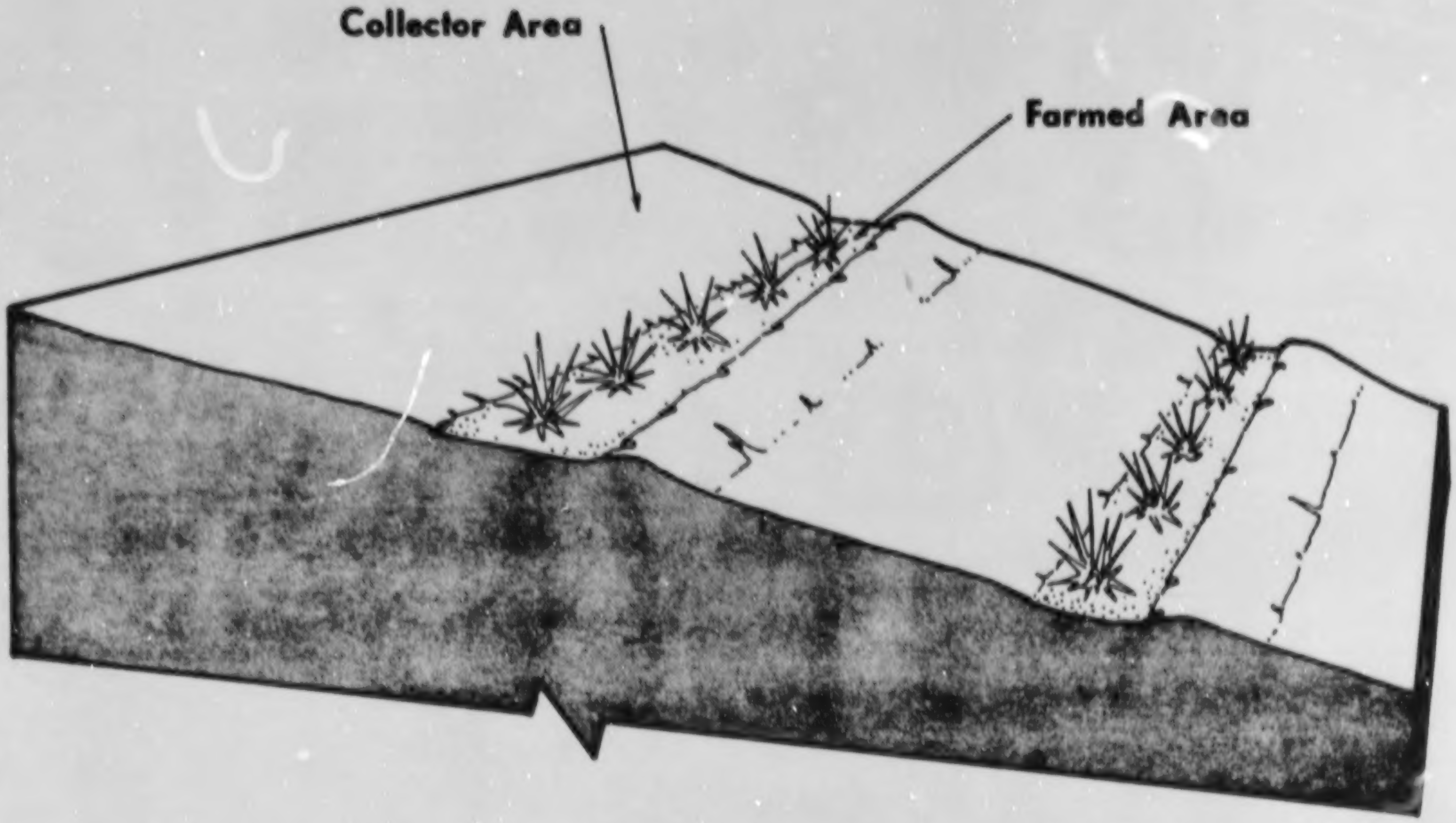
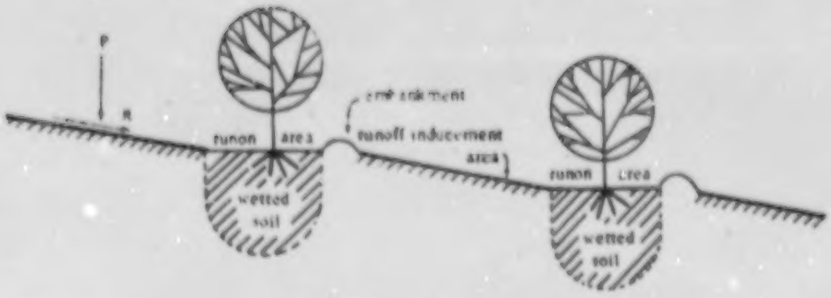
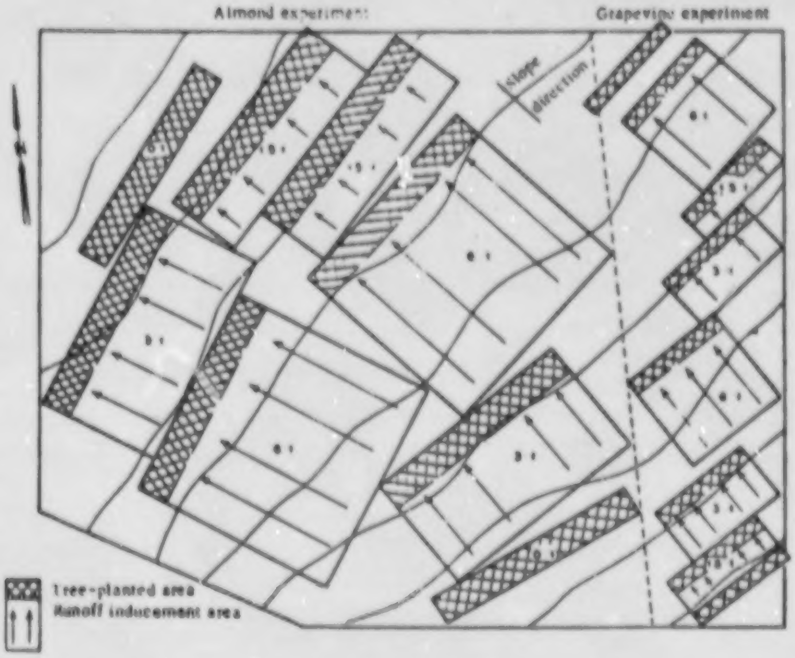

Collector Area
Farmed Area

Fig. 3. ARTIST'S CONCEPT OF DESERT STRIP FARMING


P
R
runon area
embankment
runoff inducement area
wetted soil
runon area
wetted soil

Profile of runoff-irrigated orchard (schematic)


Almond experiment
Grapevine experiment
slope direction
N
Tree-planted area
Runoff inducement area

Map of runoff orchard experiment, Gilat.

Fig. 4. Runoff-irrigated orchard experiments in Israel.

the dike or to break through. The solution of this problem may require the relocation or widening of a spillway from the dike above. The difficulty might be solved by a diversion dike or ditch above to increase the spread of the water. Possibly the dike may have to be raised in height or reinforced.

2. Dry areas not receiving water. Often a short ditch leading water to the dry spot will solve the problem, or a dike may be required to divert water to the dry area. A pipe may have to be put through a dike to let water come through to the dry spot. Sometimes partial dike or spillway relocation is necessary. The designer should not expect to irrigate all of the spreader area in each run. If 65 to 85 percent of the area can be given a good wetting in the average water run, a successful design has been attained.
3. Too much or too little water coming through the openings in flood spreaders. This fault can be corrected by reducing or increasing the size of the opening.
4. Too rapid concentration of flowing water in the system. This flow may require more small plugs or dikes in natural drainage ways, in old road ruts and trails, in low spots, in basin lips, in the borrow pits, etc., to turn out the water frequently and keep it in a sheet. Often in wild flooding systems, only the primary dikes are constructed at the beginning and the secondary dike construction is delayed until a flow of water has gone through the system, thus indicating where the secondary dikes will do the most good.
5. Improper division of water flowing into the borrow pit and that moving directly towards the next dike in flood spreaders. Corrections can be made with ditches or wing dikes.

Common maintenance problems

Maintenance of water-spreading systems should be given prompt and careful attention to avoid much heavier costs later. If sediment accumulation is slow, the maintenance costs usually decline to a fairly low figure after about the third year. By this time, the weak spots have been strengthened and the flaws in design have been corrected in connection with maintenance work. In addition, the dikes have settled and have in some cases become partially covered with soil-binding vegetation. On the other hand, if sediment accumulation continues to be great, there may be heavy annual maintenance work to raise the dikes and adjust dike design as needed.

In some cases, channels behind diversion dikes may have to be cleared of sediment. The elevation of the floor of the diversion may have to be raised to provide sufficient flow in channels made inadequate by sedimentation.

Very often heavy maintenance costs on a waterspreading system can be reduced by improving vegetation on the upper watershed to help prevent the runoff from coming down in one big flash flood of terrific force but short duration. Delayed runoff may save dikes from being overtopped and breached. It will also reduce the amount of sediment carried from the watershed and stream channel into the spreading system.

Some of the more common maintenance problems are as follows:

1. Gullying at the spillways. Slight gullying at the spillways is frequent and nothing to cause grave concern. If the gullies spread or entrench quickly it may be necessary to make the spillway wider by tearing down some of the dike at the spillway end in order to give the water more spread space. More openings or pipes may have to be put through the dike in order to cut down the amount of water going to the spillway.
2. Excessive widening or plugging of the spreader dike spillway. Excessive widening may occur as a result of erosion at the end of the dike. It can usually be stopped by building a riprap face on the end of the dike. Plugging is usually caused by deposits of sediment or debris which may have to be removed or smoothed out from time to time.
3. In straight channels paralleling dikes, obstructions, such as rocks, drift, shrubs, or earth projections, may deflect the current against the loose dike fill causing the dike to wash or cave. Remove such obstructions to permit free flow.

4. Gullying in the return or excess water channel. It is well to note the tail or excess water area particularly after a big flow. If head cuts are developing, direct the water to a more favorable location if possible. At least keep it in a thin sheet where it moves over areas likely to erode. It is sometimes impossible to avoid some erosion for a few years while an artificially sloped and vegetated area develops an adequate cover which will take the flow without eroding. The maintenance of the excess channel may require protection from grazing by fencing.

LITERATURE

Hillel, D. 1967. Runoff inducement in arid lands. Final technical report submitted to U.S. Dept. of Agriculture. Volcani Inst. of Agri. Res. and Hebrew Univ. of Jerusalem. Rehovolt, Israel. 142 pp.

National Academy of Sciences. 1974. More water for arid lands--promising technologies and research opportunities. Board of Science and Technology for International Development, National Academy of Sciences. Washington, D.C. 153 pp.

Stokes, C. M., R. D. Larson and C. K. Pearse. 1954. Range improvement through waterspreading. Foreign Operations Administration, Washington, D. C. 36 pp.

ECONOMIC WATER HARVESTING SYSTEMS FOR INCREASING WATER SUPPLY IN ARID LANDS

C. Brent Cluff[1]
and
Gordon R. Dutt[2]

INTRODUCTION

Water harvesting systems may be defined as artificial methods whereby precipitation can be collected and stored until it is beneficially used. The system consists of a catchment made more impervious by artificial means than it was in its natural state. A catchment can be made more impervious using the following methods: (1) land surface alteration, (2) chemical treatments, (3) soil cementation treatments, and (4) ground cover modification. In land alteration, runoff can be increased by (1) clearing and smoothing, (2) shaping, and (3) compaction. The two basic types of chemical treatment are the use of water repellents such as silicones and clay dispersants such as sodium salts. Soil cementation treatments include the mixing of asphalt, cement, resins, and polymers into the soil. Ground covers that have been used for catchment construction can be classified as (1) exposed membranes including butyl, plastic, and asphalt, (2) covered membranes, generally utilizing gravel to cover plastic sheeting, (3) reinforced cement-mortar coated plastic, (3) sheet metal, (5) concrete, (6) reinforced asphalt, and (7) asphalt planking.

Various methods of storage have been used with the above methods of catchment construction. These methods include (1) above-ground tanks and (2) lined reservoirs.

The above-ground tanks have been constructed from (1) steel, (2) reinforced concrete, (3) metal grain bins with flexible liners, (4) butyl bags, (5) wire reinforced stucco, and (6) using railroad tank cars and other types of surplus tanks.

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The earth reservoirs have been sealed with various types of membrane liners and by mechanical and chemical treatments. The membranes that have been used include (1) plastic and butyl rubber sheeting, (2) unreinforced and reinforced asphalt membranes, and (3) reinforced cement-mortar coated plastic. Mechanical and chemical treatments include (1) mechanical compaction with and without the use of a compacting agent such as enzymes, (2) clay dispersants which are also sometimes compacted, (3) water repellants, (3) polymers such as SS-13, and (5) bentonite (Boyer and Cluff 1972).

A very important aspect of storage is evaporation control. Evaporation has been controlled by use of chemicals such as long chain alcohols, by use of floating and suspended covers of butyl rubber and plastic sheeting on small tanks, and by completely filling the tank with rock.

There is considerable variation in the cost longevity and efficiency of the above methods of catchment and storage construction. The above systems would need to be evaluated for each site in order to select the optimum system. This paper will discuss in more detail the specific systems developed and/or tested at the Water Resources Research Center, University of Arizona, over the past ten years. In general, these systems are among the most economical of those mentioned above. These water harvesting systems were developed in order to (1) provide a dependable supply of stock water, (2) provide a high quality water for domestic and industrial supplies, and (3) extend agriculture into lands presently uncultivated due to lack of water.

WATER HARVESTING CATCHMENTS TESTED AT THE UNIVERSITY OF ARIZONA

Many of the more economical materials mentioned in the Introduction have been tested in the Water Harvesting Program at the University of Arizona; however, the most expensive materials such as sheet metal, concrete, asphalt panels, and asphaltic pavements, were not tested. The results from small plots using exposed unreinforced asphalt membranes have shown that, although relatively inexpensive, this method is undesirable due to cracking caused by oxidation, plant germination, and swelling and shrinking of the soil subgrade. Myers, Frasier, and Griggs (1967) have experienced these difficulties in their work with exposed, unreinforced membranes. Based on the results of small plot tests, economics, and experience of other reserachers, large scale testing at the University of Arizona has been limited to the following treatments: (1) compacted earth, (2) sodium, (3) gravel covered plastic, and (4) reinforced chip-coated asphalt catchments. A discussion of these catchments follows.

Compacted earth (CE)

The Public Works Department of Western Australia initiated in 1948 a program of construction of what they called "Roaded Catchments" (Carder 1970). These catchments consisted of clearing, shaping, and contouring to control length and degree of slope and compacting with the aid of pneumatic rollers. An estimated 2500 roaded catchments have been installed principally to supply water for livestock use (Hollick 1973). These average approximately two acres in size. There are also 21 roaded catchments totaling 1745 acres (706 hectares) and ranging in size from 30 to 175 acres (12.1 to 70.8 hectares) presently being used to furnish domestic water for small towns in Western Australia.

This relatively large scale use in Australia of the compacted earth catchment attests to their utility. A one acre (0.4 hectare) compacted earth catchment was constructed in the spring of 1970 at Atterbury Experimental Watershed located near Tucson, Arizona. A design similar to those in Australia was used. Two 300 foot (121.9 meters) long drains spaced 50 feet (15.2 meters) apart collected water from 25 foot (7.6 meters) long slopes. The drainage channels were covered with plastic and gravel to prevent erosion and water loss. The catchment was shaped by a grader following a one-half inch (1.27 centimeters) rainfall. The plot was then smoothed using a tractor-drawn rotary rock rake (Cluff et al. 1972). This proved to be an excellent method of smoothing. Following an additional one-half inch (1.27 centimeters) of precipitation, the plot was compacted using a 26 ton (23.6 metric tons) vibratory drum roller. The drainage channels were also lined at this time. The total cost8 of the catchment was approximately $250 including wages at $3.50 per hour. The cost would be more if the catchment site were more remote, unless several catchments were installed at one time. For larger catchments, the cost should be less than $150 per acre ($370.60 per hectare), the cost being primarily dependent on the cost of clearing and shaping. The smoothing and compaction costs on a large plot would be relatively low. There has been little maintenance since the plot was installed. Carder (1970) indicated that maintenance would consist primarily of weed control, and if care were taken not to disturb the surface while controlling weeds, the road surface should improve with age.

During the 18-month project period, a total rainfall of 19.73 inches (50.11 centimeters) occurred. The compacted plot yielded 6.96 inches (17.68 centimeters) or 35.3 percent of the total rainfall. This represented an increase of 4.86 inches (12.34 centimeters) over the water yield from a control plot. The amount of precipitation required to initiate runoff was about 0.20 inches (0.51 centimeters).

Assuming a life of 20 years, an interest rate of six percent, and an efficiency of 35 percent in a 12-inch (30.48 centimeters) rainfall area, the cost of water harvested from the compacted plot would be approximately 18 cents per thousand gallons ($0.048 per cubic meter). This price does not include weed control costs. Economy of scale would reduce this cost even further on larger catchments.

Sodium treated catchments

Results from previous research (Kemper and Noonan 1970) (Cluff et al. 1971) indicate that small amounts of sodium, when applied to the surface of desert soils where there is little or no vegetation, will cause a dramatic reduction in infiltration rate. The effect, however, has been found to be temporary. Sodium does cause a clay migration from the surface. Clay lenses

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*All cost estimates presented in this paper are in U.S. dollars and are based on 1972 cost and methods of construction in Arizona unless otherwise indicated.

have been created in the laboratory and the field through the use of a relatively heavy treatment of sodium chloride. These clay lenses have been found to be migratory in the sandy loam soil (clay content = 11 percent) at Atterbury Experimental Watershed. When the lenses are close to the surface, they have a large effect on runoff. As the lenses move down in the soil profile, the effect becomes negligible.

The application of a relatively light treatment of sodium (up to 15 exchangeable sodium percentage in the surface inch) to a grass-covered soil does not result in a significant change in infiltration rate. The maintenance of a grass cover seems to be incompatible with the use of a light treatment of sodium chloride to increase runoff.

Results have indicated that sodium chloride can be used in increasing runoff where the soil is bare. Periodic disking and smoothing of the soil surface may be needed along with retreatment of sodium chloride in order to maintain a low infiltration rate. The disking may also be required to return the clays to the surface. This method of treatment would require shaped catchment areas to minimize the length and degree of slopes so that erosion would not be excessive.

Perhaps the most effective use of sodium chloride is in conjunction with the compacted earth catchment. The sodium not only renders the catchment more impervious but is an effective way to control weeds. Weeds are the major maintenance problem in compacted earth catchments. The Compacted-Earth Sodium-Treated (CEST) Catchment has been field tested on a one acre site at Page Experimental Ranch. The catchment was prepared in the spring of 1971 in the same way as the CE Catchment at Atterbury Experimental Watershed. After shaping, the plot was tototilled to destroy soil structure. Five tons of granulated salt were then added using a fertilizer spreader. The granulated salt was mixed into the upper two inches of soil and the soil surface smoothed using the rotating tractor-drawn rock rake. Following a 0.4 inch (1.01 centimeters) rainfall, the catchment was compacted with a drum roller. The total cost of the CEST Catchment was approximately $450. Economy of scale should reduce the cost of this catchment to less than $350 per acre. This catchment was constructed to serve a dual purpose. Grapes and deciduous fruit trees have been planted in the drainageways. Water is stored both in the soil and in a 150,000 gallon storage tank where it is available for use during dry periods. Thus, the catchment can produce both food and water. This type of dual system should be more acceptable to the general public than bare catchment areas. The efficiency of this system neglecting soil-stored water has been greater than 50 percent of the total rainfall.

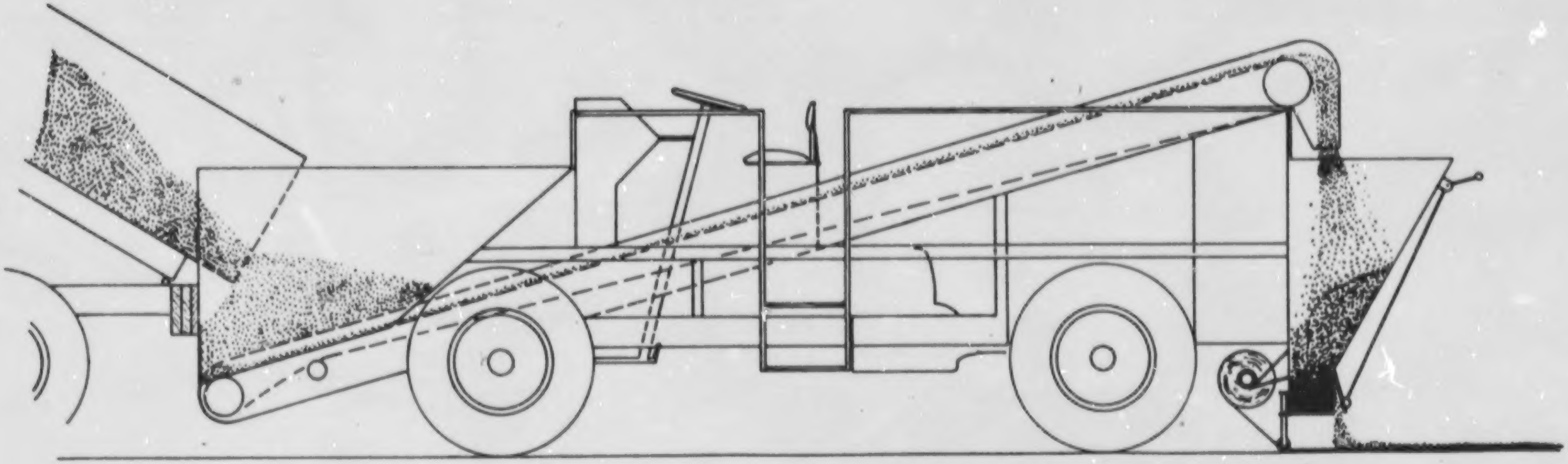
The Page CEST Catchment is located in a 16-inch (40.64 centimeters) rainfall area. Based on a 25-year amortization period and an interest rate of six percent, the cost of excess water produced at this catchment is $0.16 per thousand gallons ($0.042 per cubic meter) or $0.20 per thousand gallons ($0.0529 per cubic meter) in a 12-inch (30.48 centimeters) rainfall area. Economy of scale should reduce this cost still further on large size catchments. The above cost figures do not reflect the value of crops produced from the soil stored water. These costs are similar to those given for the CE Catchment at the Atterbury Experimental Watershed. It should be noted that the CE Catchment would be impractical at Page Ranch due to weed and grass problems.

Gravel covered plastic (GCP)

The use of exposed plastic for water harvesting has been unsuccessful (Cluff 1971) due to ultra-violet induced oxidation, wind, and mechanical damage. The use of gravel protects the plastic from sunlight and wind. Gravel covered plastic catchments were first installed at the University of Arizona in December of 1965. The six-mil (0.015 millimeters) poly-ethylene plastic in early installations is still in excellent shape.

In order to reduce costs of the gravel covered plastic catchment, two different types of automated installation were developed. One type was a plastic laying gravel chute that fits on the back of a dump truck. By means of the chute, plastic could be laid down and covered in one installation (Cluff 1968).

A more controlled method of installation of GCP catchments can be attained through the use of a self-propelled chip spreader modified in the manner shown in Figure 1. Where specialized gravel spreading equipment is



WATER RESOURCES RESEARCH CENTER UNIVERSITY OF ARIZONA		
TITLE PROPOSED MODIFICATION OF CHIP SPREADER FOR INSTALLATION OF PLASTIC MEMBRANES		
DESIGNED BY	DRAWN BY	DATE
A.R HURLEY		11/10/69

Figure 1

not available, the catchment has been installed at a rate of 2000 ft^2 (185.8 square meters) per hour using a front-end loader and a crew of five.

Large areas of the world have sufficient gravel in the upper soil profile to cover the plastic. Because of this, a machine was developed that would extract the gravel from the soil, lay plastic, and cover the plastic with the extracted rock. Considerable research effort was expended in the successful testing of this type of machine which was called the Gravel Extracting Soil Sifter (GESS) (Cluff et al. 1971).

A schematic of the GESS is given in Figure 2. In areas where the GESS is not available or for remote sites, hand labor can be utilized.

The efficiency of a graveled plastic catchment is given by:

$$E = 100 \sum_{1}^{n} (P_i - L)/(\sum_{1}^{n} P_i + \sum_{1}^{m} S_j)$$

L = Amount of water trapped by the gravel cover.

m = Total number of storms which have a rainfall total less than L.

n = Total number of storms which have a rainfall total greater than L.

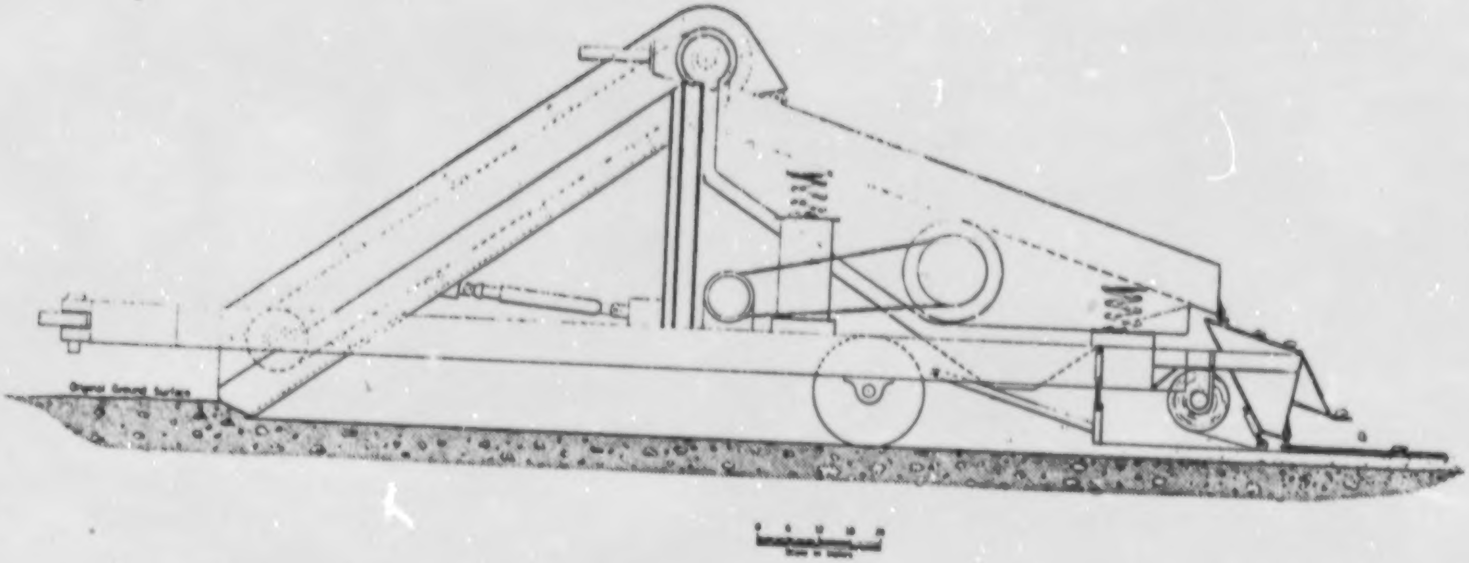
E = Efficiency of the plastic catchment for period when n + m storms occur.

P_i = Precipitation total of ith storm whose total is greater than L.

S_j = Precipitation total of jth storm whose total is less than L.

The loss L has been found to stabilize at approximately 0.11 inches (0.28 centimeters) for a properly constructed catchment. In a rainfall regime similar to Tucson, the efficiency would be approximately 70 percent.

A catchment is properly constructed if the plastic is covered with the minimum size and depth of gravel needed to provide a complete cover and resist erosion. Figure 3 contains the results of a study which indicates what this minimum cover would be for different slopes (Cluff et al 1971). This figure shows that on a 10 percent slope 100 feet (30.48 meters) long, a one-half inch cover of 3/16 to 3/8 inch (0.48 to 0.95 centimeters) gravel will withstand an 18-inch (45.7 centimeters) per hour intensity rainfall. In contrast with the CE and CEST catchments, the GCP Catchment produces sediment free water, a primary consideration in domestic supplies. The cost depends on the method of installation. In general, it would be approximately $1000 per acre ($2475 per hectare) for large catchments installed


Original Ground Surface

GRAVEL EXTRACTING SOIL SIFTER
SCHEMATIC FOR PROTOTYPE II

WATER RESOURCES RESEARCH CENTER
UNIVERSITY OF ARIZONA
TUCSON, ARIZONA

Design by: [illegible] and [illegible]
Drawn by: [illegible]
Date: August 1971

Figure 2

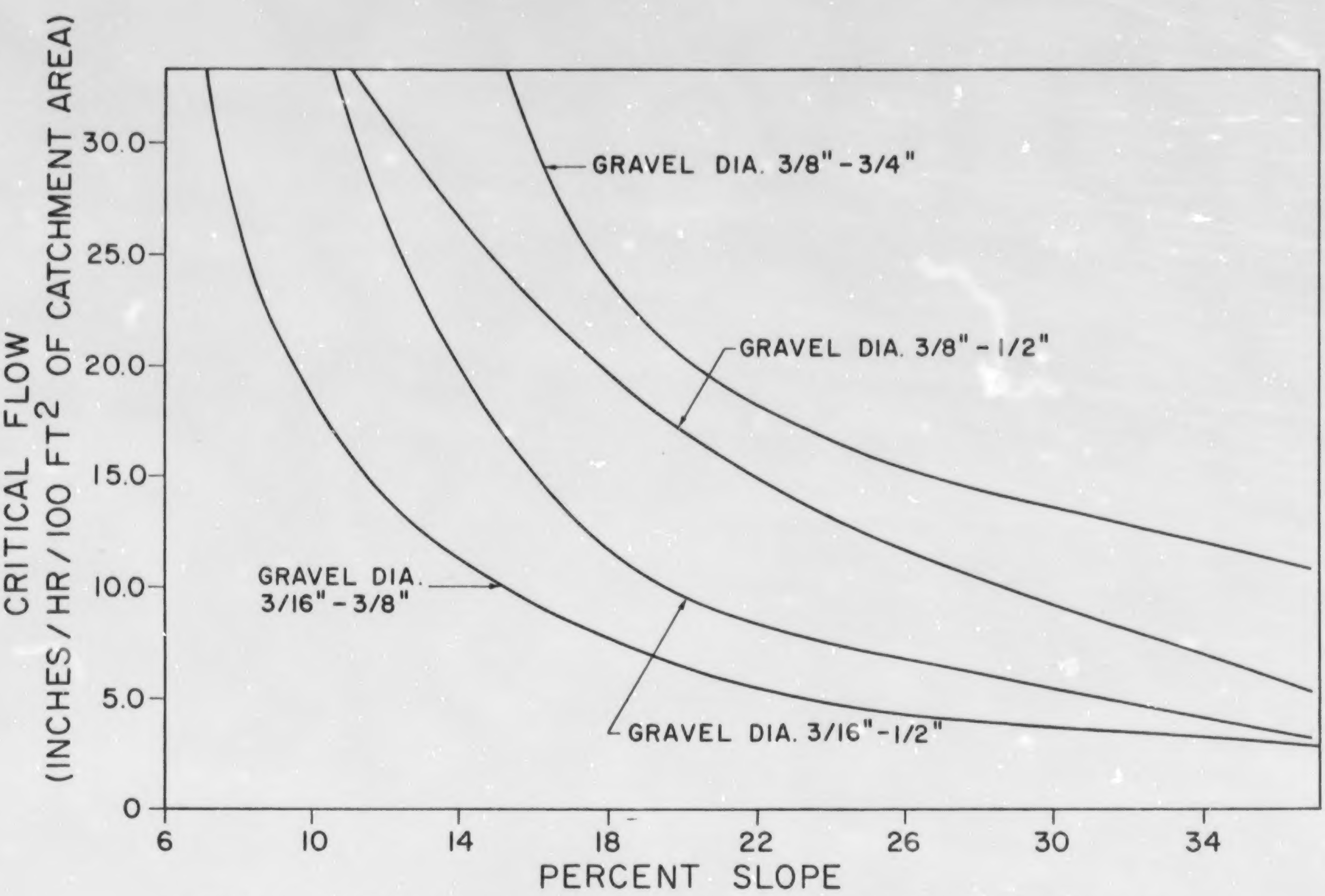


FIGURE 3. CRITICAL FLOW VERSUS SLOPE FOR SELECTED SIZE OF GRAVEL COVER. (KIRKLAND, 1969)

with an improved version of the GESS using ten mil (0.0254 millimeters) polyethylene plastic. The use of imported gravel would increase the cost to over $1500 per acre ($3713 per hectare). The projected life of a properly constructed and maintained GCP catchment is twenty-five years. With a 70 percent efficiency and a 6 percent amortization rate, the cost of water would be $0.34 per thousand gallons ($0.089 per cubic meter) in a 12-inch (30.48 centimeters) rainfall zone.

Chip-Coated Reinforced-Asphalt Catchments

Frasier, Myers, and Griggs (1970) have developed the fiberglass reinforced asphalt catchment. Several of these catchments have been field tested in Arizona. Work at the University of Arizona in the area of reinforced asphalt catchments have centered around the use of plastic, both polyethlene and polypropylene, as the reinforcement material. The treatment consists of a prime coat of emulsified asphalt followed by a layer of four mil (0.0102 millimeter) polyethylene sheeting or polypropylene matting, which is then immediately covered with a top coat of emulsified asphalt and 1/8 to 3/16-inch (0.32 to 0.48 centimeters) chips. This Asphalt-Plastic Asphalt-Chip coated (APAC) catchment has many good features. It requires approximately one-third the amount of gravel as a GCP Catchment. The treatment should work on any soil type since the plastic reinforcement prevents cracking. Treatment can be completed at one time. No curing time is needed during construction. The plastic should last at least 25-30 years if the catchment is properly maintained. Retreatment would be made by sweeping loose chips from the surface and laying down a new asphalt and chip protective coating. Based on the use of similar treatments in the roofing industry, retreatment would probably be needed every 10 to 15 years. Results from small plots indicate the catchment will cost at least twice as much as the GCP Catchment but will have an efficiency from 90 to 95 percent. This treatment has sufficient merit, and large scale testing is planned.

WATER STORAGE METHODS COMPATIBLE WITH WATER HARVESTING CATCHMENTS TESTED AT THE UNIVERSITY OF ARIZONA

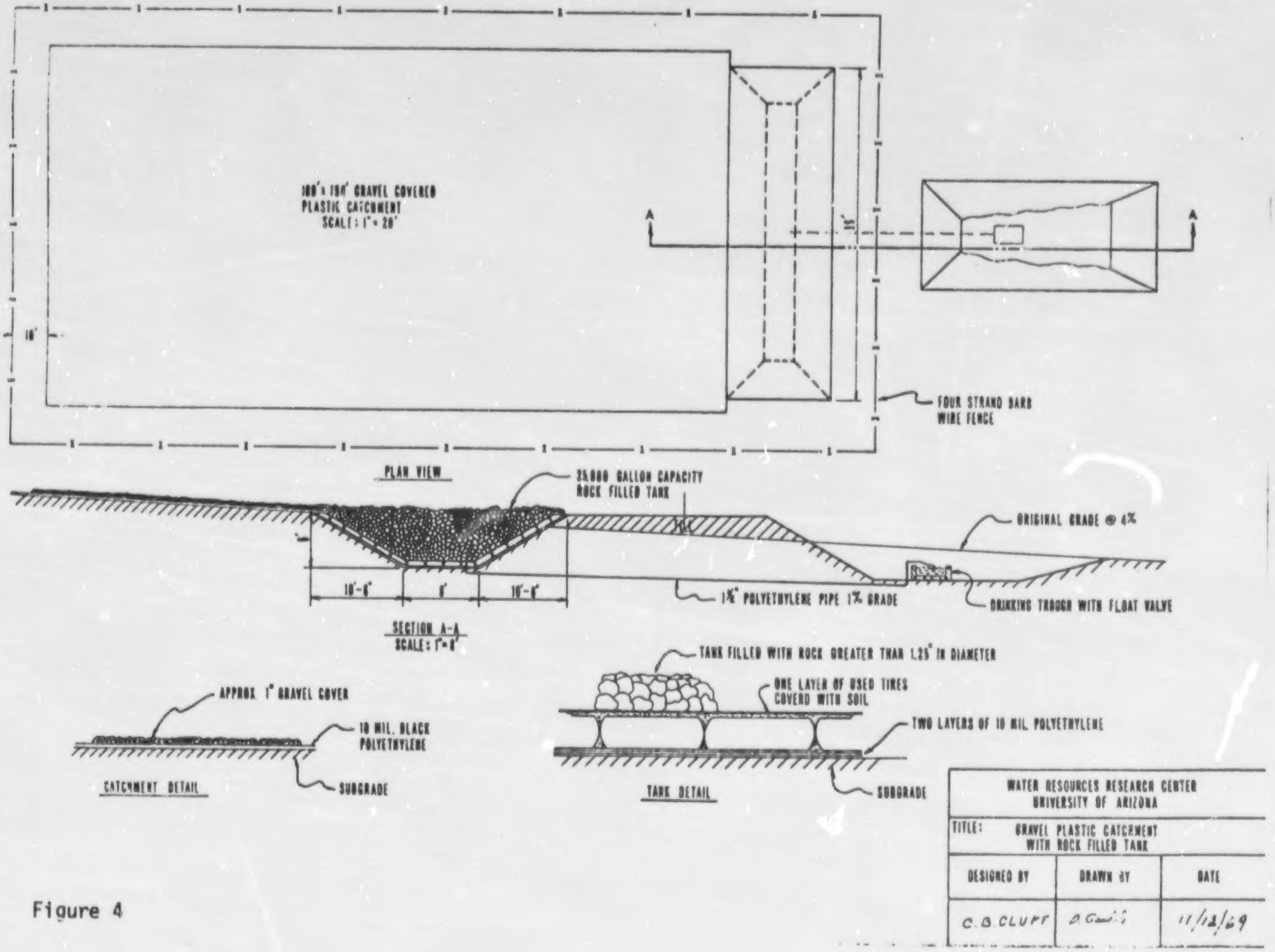
In general, the water storage techniques tested at the University of Arizona have been related to stock water supplies and, consequently, are limited in size. The basic treatment would also be suitable for larger reservoirs, with the possible exception of the rock-filled tank or those tanks utilizing the suspended cover for evaporation control. The seepage and evaporation control methods outlined here can also be used on existing or new reservoirs that are filled from other sources of water.

Plastic-lined rock-filled reservoir

The construction of this tank was prompted by the availability of commercial rock pickers which make the collection of rock for small tanks economical. Although decreasing storage by over 50 percent, the rock greatly reduces evaporation loss and practically eliminates any chance of mechanical damage including vandalism.

The tank is first excavated, then the surface is raked smooth. Two or three layers of ten-mil (0.0254 millimeters) polyethylene plastic is then laid down and covered with used rubber tires. The tires are filled with silty clay cover material to reduce the significance of any holes that may inadvertantly occur in the plastic. The tires protect the plastic liner as rocks are added to the tank. In the United States, used rubber tires can be easily obtained at no cost. In areas where used tires are difficult to obtain, a 12-18 inch (30.48 to 45.72 centimeters) layer of soil on slopes less than 1:3 or a reinforced coat of cement-mortar could be used on the tank to protect the plastic. Three rock-filled tanks have been constructed in Arizona using a rotary drum commercial rock picker in areas containing sufficient rock to make the system economical. The cost is dependent upon the site and method of collection of the rock (Cluff et al. 1972). The tanks were constructed for a cost of approximately $2300 for 25,000 gallons (94.6 cubic meters) net storage with $1600 expended for the filling of the tank with rock. A reel-type rock picker was tested in connection with the construction of the above tanks. These tests indicated that the use of this type of picker should reduce costs by 50 percent.

The rock-filled tank is very compatible with the GCP Catchment. The larger rock can go into the tank with the smaller rock being used to cover the plastic on the catchment. A schematic of a water harvesting system of this type is shown in Figure 4.


100' x 190' GRAVEL COVERED
PLASTIC CATCHMENT
SCALE: 1" = 20'
10'
35'
A
A
FOUR STRAND BARB
WIRE FENCE
PLAN VIEW
25,000 GALLON CAPACITY
ROCK FILLED TANK
ORIGINAL GRADE @ 4%
10'-6"
8'
10'-6"
1¼" POLYETHYLENE PIPE 1% GRADE
DRINKING TROUGH WITH FLOAT VALVE
SECTION A-A
SCALE: 1" = 8'
TANK FILLED WITH ROCK GREATER THAN 1.25" IN DIAMETER
APPROX. 1" GRAVEL COVER
ONE LAYER OF USED TIRES
COVERD WITH SOIL
10 MIL. BLACK
POLYETHYLENE
TWO LAYERS OF 10 MIL. POLYETHYLENE
CATCHMENT DETAIL
SUBGRADE
TANK DETAIL
SUBGRADE

WATER RESOURCES RESEARCH CENTER UNIVERSITY OF ARIZONA		
TITLE: GRAVEL PLASTIC CATCHMENT WITH ROCK FILLED TANK		
DESIGNED BY	DRAWN BY	DATE
C. B. CLUFF	D. Gami.i	11/12/69

Figure 4

Plastic-lined concrete-coated or earth-covered

The various methods of seepage control were outlined in the introduction. Plastic lining, if properly covered, offers a positive method of seepage control that is very competitive with other methods. Tests have indicated that a layer of silty soil, or a three-quarter inch (1.90 centimeter) layer of wire mesh reinforced cement-mortar will greatly reduce the seepage loss through holes that may inadvertently be placed in the plastic liner (Boyer and Cluff 1972). The reinforced mortar coating is placed directly on the plastic and has proven to be an effective cover to use on steep slopes. This coating may either be placed using gunnite equipment or can be hand plastered. The cost of this cover is less than twenty cents per square foot ($2.15 per square meter).

In order to reduce the cost of installation on larger reservoirs, the same equipment developed for laying graveled plastic catchments can be used for laying and covering of plastic liners with soil (Cluff 1968). On smaller tanks, of the size used for stock purposes, the soil covering is generally installed using hand labor. A tank using a covering of soil in the bottom and reinforced mortar on the sides is shown in Figure 5. The economy and strength of the reinforced mortar covered plastic makes it practical to construct a walk-through cattle trough that is directly connected to the tank. This design avoids the need for a float valve which is subject to malfunction and vandalism. The use of the mortar covering also makes it possible to run water directly from the catchment into the tank, thus avoiding any chance of stoppage.

A Coupled-Expanded-Polystyrene Asphalt-Chipcoated (CEPAC) Raft can be used for evaporation control (Cluff,1972). This system, first tested in the spring of 1972, is essentially 100 percent effective in preventing evaporation loss for the area covered. Any size of polystyrene sheets can be coupled together. Those tested at the University of Arizona have been primarily one inch (2.54 centimeters) thick, four by four foot (1.62 x 1.62 meters) sheets. These sheets are coated with emulsified asphalt and immediately covered with 1/16 to 1/8 inch (0.16 to 0.32 centimeters) chips. The sheets are coupled together using a coupler made out of two short lengths of slotted 1 1/2 inch (3.81 centimeters) PVC pipe. An outer frame

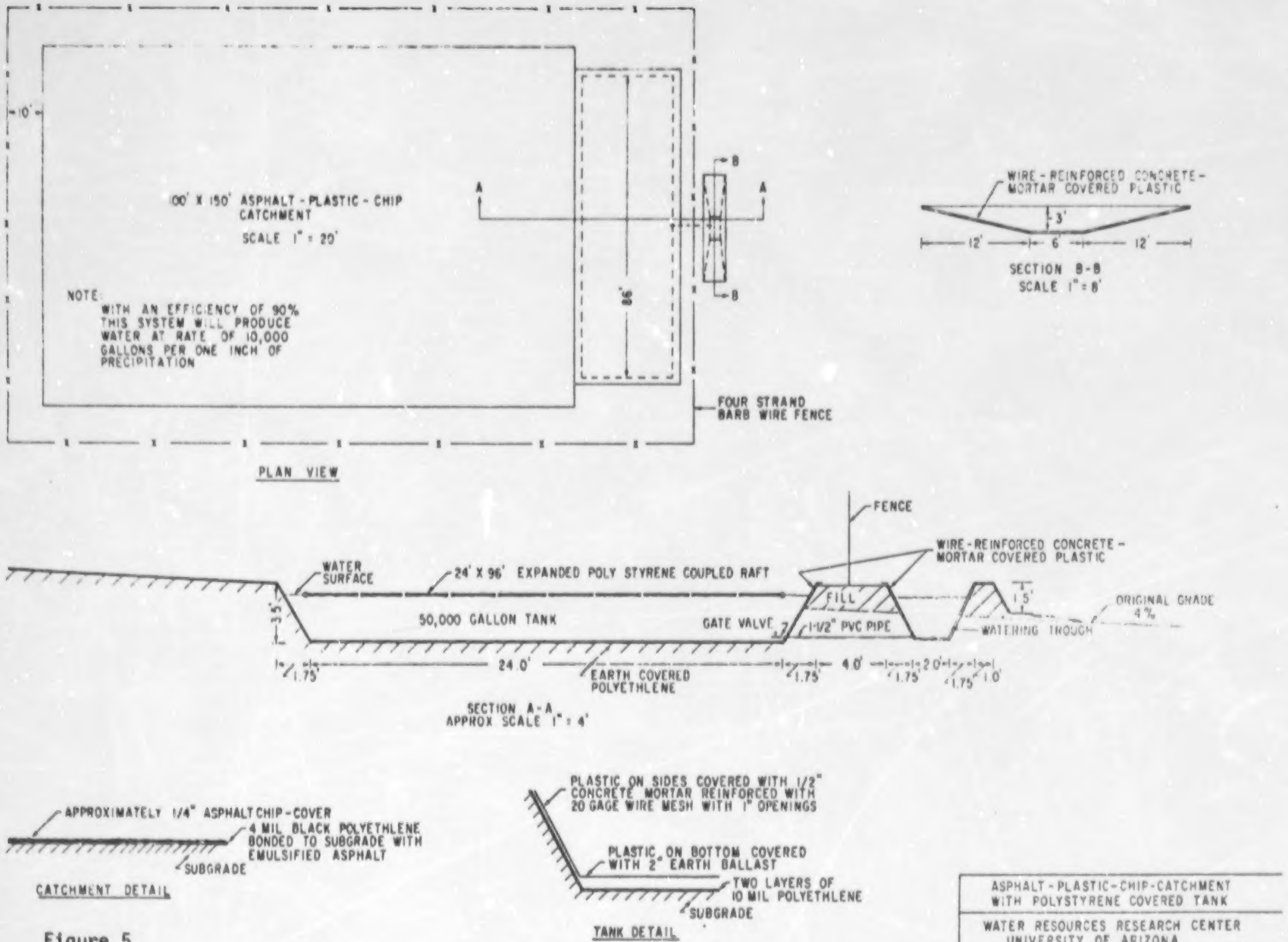

10'
100' X 150' ASPHALT - PLASTIC - CHIP CATCHMENT
SCALE 1" = 20'
NOTE:
WITH AN EFFICIENCY OF 90% THIS SYSTEM WILL PRODUCE WATER AT RATE OF 10,000 GALLONS PER ONE INCH OF PRECIPITATION
96'
A
A
B
B
FOUR STRAND BARB WIRE FENCE
PLAN VIEW
WIRE - REINFORCED CONCRETE - MORTAR COVERED PLASTIC
3'
12'
6'
12'
SECTION B-B
SCALE 1" = 8'
FENCE
WATER SURFACE
24' X 96' EXPANDED POLY STYRENE COUPLED RAFT
WIRE - REINFORCED CONCRETE - MORTAR COVERED PLASTIC
3.5'
50,000 GALLON TANK
GATE VALVE
FILL
1-1/2" PVC PIPE
1.5'
ORIGINAL GRADE 4%
WATERING TROUGH
1.75'
24.0'
EARTH COVERED POLYETHLENE
1.75'
4.0'
1.75'
2.0'
1.75'
1.0'
SECTION A-A
APPROX SCALE 1" = 4'
APPROXIMATELY 1/4" ASPHALT CHIP - COVER
4 MIL BLACK POLYETHLENE BONDED TO SUBGRADE WITH EMULSIFIED ASPHALT
SUBGRADE
CATCHMENT DETAIL
PLASTIC ON SIDES COVERED WITH 1/2" CONCRETE MORTAR REINFORCED WITH 20 GAGE WIRE MESH WITH 1" OPENINGS
PLASTIC ON BOTTOM COVERED WITH 2" EARTH BALLAST
TWO LAYERS OF 10 MIL POLYETHLENE
SUBGRADE
TANK DETAIL

Figure 5

ASPHALT - PLASTIC - CHIP - CATCHMENT WITH POLYSTYRENE COVERED TANK		
WATER RESOURCES RESEARCH CENTER UNIVERSITY OF ARIZONA		
DESIGNED BY:	DRAWN BY:	DATE
CB CLUFF	L. DAVIS	JULY 9, 1972

of 1 1/4 inch (3.17 centimeters) PVC pipe filled with water provides a protective bumper for the rafts which have been constructed up to 1600 square feet (148.6 square meters). These rafts can be coupled together to cover as large a body of water as desired. The cost of this system is less than ten cents per square foot ($1.07 per square meter).

A suspended cover of butyl or reinforced plastic would be recommended (Cluff et al. 1972) for smaller tanks used for domestic control in which it is desirable to keep out foreign material or eliminate algae growth.

Sodium treated reservoirs

When there is sufficient clay in the soil and the incoming water is higher in sodium than calcium, the use of sodium salt is the most economical treatment for seepage control. The 150,000 gallon (567.8 cubic meters) tank at Page Ranch, constructed in connection with the salt treated catchment, was sealed in 1971 with sodium chloride at the rate of five tons (11.20 metric tons per hectare) per acre. The seepage loss at the tank appears to be insignificant, and due to the fact that the incoming water has more sodium than calcium, the life of the seal is indefinite. Evaporation is controlled at the Page Ranch tank through the use of CEPAC Rafts.

DISCUSSION AND CONCLUSIONS

Table 1 gives a summary of the costs and estimated life of the catchments developed at the University of Arizona. Each site and potential water use should be examined in order to determine which catchment and method of storage to use.

The use of the CE and CEST Catchments are limited to areas where soil conditions are favorable. Both the CE and CEST Catchments should not be built where soils are difficult to compact. Tests to date have indicated that clay content should not be less than five nor greater than 35 percent. For soils with the higher clay content, it would also be important to have more sand than silt, otherwise erosion problems would be unsolvable.

Water produced from a CE or CEST Catchment contains considerable sediment. In the case of the CEST Catchment, this sediment is finely dispersed and will remain in suspension. Although salt treated, the water

TABLE 1

RELATIVE COST AND EFFICIENCY OF CATCHMENTS DEVELOPED AT THE UNIVERSITY OF ARIZONA

December, 1972

Catchment Methods	Approx. Cost per Square Yard	Approx. Cost per Acre	Efficiency in Percent	Est. Life
Compacted Earth (CE)*	$0.03-0.05	$150-250	30-60	Indefinite
Compacted Earth Sodium Treated (CEST)*	$0.06-0.10	$300-500	40-70	Indefinite
Graveled Plastic (GCP)**	$0.20-0.50	$1000-2400	60-80	20-25 years
Asphalt-Plastic Asphalt-Chip-Coated (APAC)***				
Polyethylene Reinforced	$0.50-0.60	$2400-2900	85-95	10-15 years
Polypropylene Reinforced	$0.90-1.00	$4400-4900	85-95	10-15 years

* Prices and efficiency of CE and CEST Catchments are dependent on soil type, cost of clearing and shaping. Maintenance consists of weed removal and recompaction as needed. Additional NaCl may be required periodically prior to recompaction for maintenance of the CEST Catchment.

** The variation in price of the GP Catchment is primarily dependent on the cost of the gravel and to a lesser extent the cost of clearing and shaping. The cost of the 10 mil black polyethylene plastic to be used is relatively stable. Maintenance consists of adding gravel if necessary on exposed portions of the catchment.

*** Prices of the APAC systems are based on projection of small plots. Larger installations need to be made to firm up prices. Maintenance consists of recoating with asphalt and chips every 10-15 years.

from a CEST Catchment has less than 500 parts per million total salinity and can be used for most purposes including agriculture. Although more expensive, the CEST Catchment is generally preferred over the CE Catchment since the sodium not only increases the efficiency of the catchment but also serves as an herbicide which reduces maintenance costs.

A sodium treated tank would probably be the best to use in conjunction with a CE or CEST Catchment. Periodic retreatment of the tank may be necessary with a CE Catchment.

A graveled plastic catchment should be considered where gravel is economically available, and the soil condition is not suitable for a CE or CEST Catchment, and/or a sediment-free water is desired. Generally, a plastic-lined reservoir would be used in conjunction with the GCP Catchment. A rock filled tank should be considered with the GCP Catchment if there is sufficient rock in the area and vandalism is a problem. Otherwise, a CEPAC raft covering would be recommended for evaporation control, unless the water were to be used directly for domestic use. In the latter case, a suspended cover would be recommended.

The APAC system would be used in areas where (1) soil or gravel conditions are such as to make the CE, CEST or GCP Catchments impractical and/or (2) rainfall and/or storage considerations were such that a high efficiency would be needed to maintain a firm water supply. In general, the same type of storage system used for the GCP Catchment could be used for the APAC system. The size of the storage reservoir could be reduced due to the higher efficiency of the APAC system.

Although more research is needed, costs of installation of water harvesting systems have been greatly reduced through application of modern techniques and methods described in this paper. Water harvesting should be considered whenever new water supplies for domestic and livestock use in developing arid and semiarid lands are needed. If the cost is low enough or the value of the crop is high enough, the water harvesting systems described in this paper can also be used to develop new agricultural lands where water is presently unavailable.

LITERATURE

Boyer, D. G. and C. B. Cluff. May 1968. An Evaluation of Current Practices in Seepage Control. Hydrology and Water Resources in Arizona and the Southwest. Volume 2. Proceedings of the 1972 Meetings of the Arizona Section of the American Water Resources Association and the Hydrology Section of the Arizona Academy of Science. Prescott, Arizona.

Carder, D. J. May 1970. Roaded Catchments - A Method of Increasing Runoff into Dams and Reservoirs. Technical Bulletin No. 5. Western Australian Department of Agriculture.

Cluff, C. B. March 1968. A New Method of Installing Plastic Membranes. Proceedings of the Second Seepage Symposium. ARS 41-147. Agricultural Research Service. Phoenix, Arizona.

Cluff, C. B. November 1971. Plastic Catchments for Economical Harvesting of Rainfall. Proceedings of the Tenth National Agricultural Plastics Conference. Chicago, Illinois.

Cluff, C. B. July 1972. Low-Cost Evaporation Control to Save Precious Stock Water. Arizona Farmer-Ranchman. Phoenix, Arizona.

Cluff, C. B., G. R. Dutt, P. R. Ogden, and J. K. Kuykendall. July 1972. Development of Economic Water Harvesting Systems for Increasing Water Supply. OWRR Project No. B-015-ARIZ. Completion Report. The University of Arizona, Tucson.

Cluff, C. B., G. R. Dutt, P. R. Ogden, and J. L. Stroehlein. September 1971. Development of Economic Water Harvesting Systems for Increasing Water Supply. OWRR Project No. B-005-ARIZ. Completion Report. The University of Arizona, Tucson.

Frasier, G. W., L. E. Myers, and J. R. Griggs. June 1970. Installation of Asphalt-Fiberglass Linings for Reservoirs and Catchments. Agricultural Research Service. United States Water Conservation Laboratory Report No. 8. Phoenix, Arizona.

Hollick, M. Personal Communication dated May 23, 1973. Department of Civil Engineering. The University of Western Australia.

Kemper, W. D. and L. Noonan. 1970. Runoff as Affected by Salt Treatments and Soil Texture. Soil Sci. Soc. Am. Proceedings 34:126-130.

Myers, L. E., G. W. Frasier, and J. R. Griggs. September 1967. Sprayed Asphalt Pavements for Water Harvesting. Jour. of the Irrigation and Drainage Division. Proceedings of the American Society of Civil Engineers.

Kirkland, L. A. 1969. The Gravel Cover and Catchment Efficiency in the Plastic-Lined Catchment. Master of Science Thesis. Department of Hydrology. The University of Arizona.

ESTIMATING STORM RUNOFF FROM SMALL WATERSHEDS

Martin M. Fogel[1]

INTRODUCTION

Management of a small watershed to conserve soil and water requires that the land be used within its capabilities and treated according to its needs. A land management program should include as its objectives:

- to protect the land against all forms of soil deterioration
- to rebuild eroded and depleted soils
- to stabilize critical runoff--and sediment--producing areas
- to improve grasslands, woodlands and wildlife lands
- to conserve water for beneficial water
- to reduce flood and sediment damage.

The above objectives can only be attained by the application of proper land-treatment practices and by the adequate design and operation of water control structures. The design of water control structures is based on hydrologic investigation made on a small watershed. In many cases, these studies are made on watersheds for which there is little or no information pertaining to the quantity and timing of runoff. This presentation discusses the U.S. Soil Conservation Service method for estimating water and sediment yields from a small ungaged watershed. While its initial use was intended for the more humid regions, this procedure is now used in arid regions throughout the world.

DETERMINATION OF RUNOFF FROM PRECIPITATION

While runoff data for small watersheds is generally lacking, information on precipitation is generally available for the site in question or can be obtained by extrapolation from areas where data is known. Some means is needed, therefore, to transform precipitation into runoff volume and peak flow rates.

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Storm runoff volume

For ungaged watersheds, the Soil Conservation Service (SCS) uses the following basic rainfall-runoff equation for estimating the runoff volume from a given storm:

$$Q = \frac{(P - 0.2S)^2}{P + 0.8S}$$

where Q = storm runoff, in mm
P = storm rainfall, in mm
S = a watershed factor which reflects the infiltration characteristics of the area under consideration, also expressed in mm.

A watershed index W, sometimes called a runoff curve number is related to S by the equation $W = 25{,}000/250 + S$

The watershed index depends on soil type, the general hydrologic condition of the area, the nature and extent of cover and the antecedent moisture condition at the start of the storm period which produces runoff.

Soil types are classified into four groups, the details of which are given in Table 1.

Table 1. Soil Groups for Estimation of Watershed Index W

Soil Group	Description of soil characteristics
A	Soils having very low runoff potential. For example, deep sands with very little silt or clay.
B	Light soils and/or well structured soils having above-average infiltration when thoroughly wetted. For example, light sandy loams, silty loams.
C	Medium soils and shallow soils having below-average infiltration when thoroughly wetted. For example, clay loams.
D	Soils having high runoff potential. For example, heavy soils, particularly clays of high swelling capacity, and very shallow soils underlain by dense clay horizons.

Three antecedent moisture conditions are allowed for, depending on the amount of rainfall received 5 days prior to the runoff. Details of these conditions are given in Table 2.

Table 2. Antecedent Moisture Conditions for Estimation of Watershed Index W

Antecedent Moisture Condition (AMC)	Rain in previous 5 days
I	Less than 15 mm
II	15 to 40 mm
III	More than 40 mm

Figure 1, which is more applicable to semiarid regions, and Table 3 both give values for the watershed index for various soil-hydrologic-cover combinations, assuming antecedent moisture condition II. For other antecedent moisture conditions, the value of W obtained from Table 3 must be adjusted as shown in Table 4.

Table 3. Values of Watershed Index W. (Assuming AMC = II)

Land use or cover	Farming treatment	Hydrologic Condition	Soil Group A	B	C	D
Native pasture or grassland	-	Poor	70	80	85	90
		Fair	50	70	80	85
		Good	40	60	75	80
Timbered areas	-	Poor	45	65	75	85
		Fair	35	60	75	80
		Good	25	55	70	75
Improved permanent pastures	-	Good	30	60	70	80
Rotation pastures	Straight Row	Poor	65	75	85	90
		Good	60	70	80	85
	Contoured	Poor	65	75	80	85
		Good	55	70	80	85
Crop	Straight row	Poor	65	75	85	90
		Good	70	80	85	90
	Contoured	Poor	70	80	85	90
		Good	65	75	80	85
Fallow	-	-	80	85	90	95

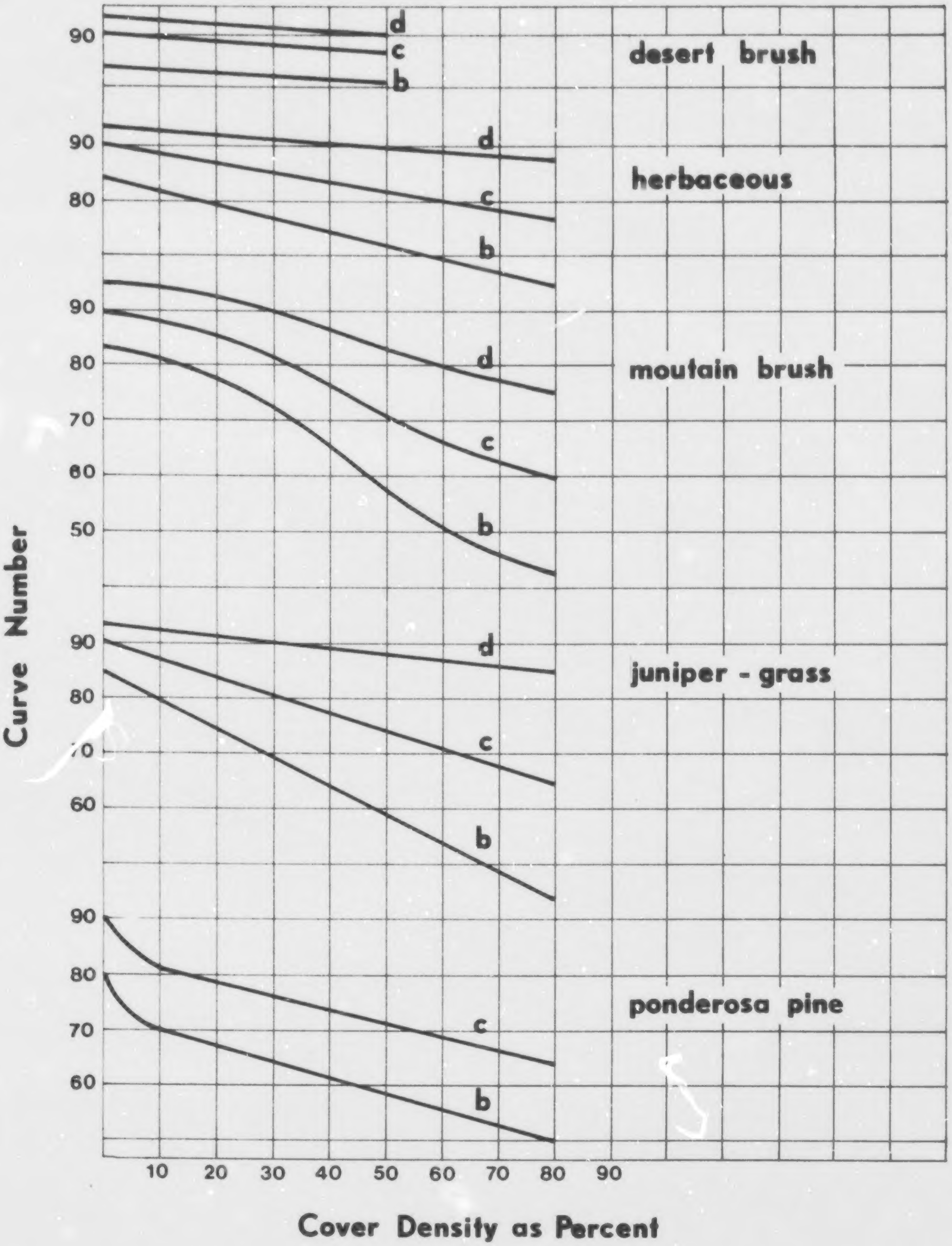

Fig. 1

HYDROLOGIC SOIL – COVER COMPLEXES
AND ASSOCIATED CURVE NUMBERS

Table 4. Adjustment of Watershed Index W for Antecedent Moisture Condition

	Corresponding value of W for	
W value for AMC = II	AMC = I	AMC = III
100	100	100
95	87	99
90	80	98
85	70	97
80	65	95
75	60	90
70	50	90
65	45	85
60	40	80
55	35	75
50	30	70
45	25	65
40	20	60
35	20	55
30	15	50
25	10	45

The meanings of the terms listed in Table 3 under the heading "Hydrologic Condition" are as follows:

a. Native pastures: Pasture in poor condition is sparse, heavily grazed pasture with less than half the total watershed area under plant cover. Pasture in fair condition is moderately grazed and with between half and three-quarters of the catchment under plant cover. Pasture in good condition is lightly grazed and with more than three-quarters of the catchment area under plant cover.

b. Timbered areas: Poor areas are sparsely timbered and heavily grazed with no undergrowth. Fair areas are moderately grazed, with some undergrowth. Good areas are densely timbered and ungrazed, with considerable undergrowth.

c. Improved permanent pastures: Densely sown permanent legume pastures with proper grazing management are said to be in good hydrologic condition.

d. Rotation pastures: Dense, moderately grazed pastures used as part of a well-planned, crop-pasture-fallow rotation are considered to be in good hydrologic condition. Sparse, overgrazed or "opportunity" pastures are considered to be in poor condition.

e. Crops: Good hydrologic condition refers to crops which form part of a well-planned and managed crop-pasture-fallow rotation. Poor hydrologic condition refers to crops managed according to a simple crop fallow rotation.

Peak flow rate

With the aid of Figure 2, a synthetic triangular hydrograph of storm runoff is developed which can be used to derive the estimated peak flow rate. The general equation is

$$q_p = \frac{KAQ}{T_p}$$

where q_p = peak runoff rate in m^3/s
A = watershed area in km^2
Q = storm runoff volume in mm
T_p = time in hours from start of runoff to peak rate
K = is a constant dependent on shape of hydrograph

Time to peak, T_p, is estimated from a consideration of both rainfall and watershed characteristics. A relationship often used is

$$T_p = 0.5D + 0.6T_c$$

where D = duration of excess rainfall in hours (for convective storms, this can be equal to the duration of rainfall).

T_c = time of concentration in hours, which is estimated from the following equation:

$$T_c = 4L^{0.77}\ S^{-0.38}$$

where L = length of the watershed along the main stream from the outlet to most distant ridge in km.

S = average slope of the main stream, a dimensionless ratio of difference in elevation between outlet and most remote point to length of watershed L.

For most cases, the constant K has a value of 0.75 if the units are similar for both sides of the peak flow equation.

ESTIMATION OF SEDIMENT YIELD

Erosion of the land creates serious problems in agriculture and water resources management through the removal of fertile soil and its subsequent

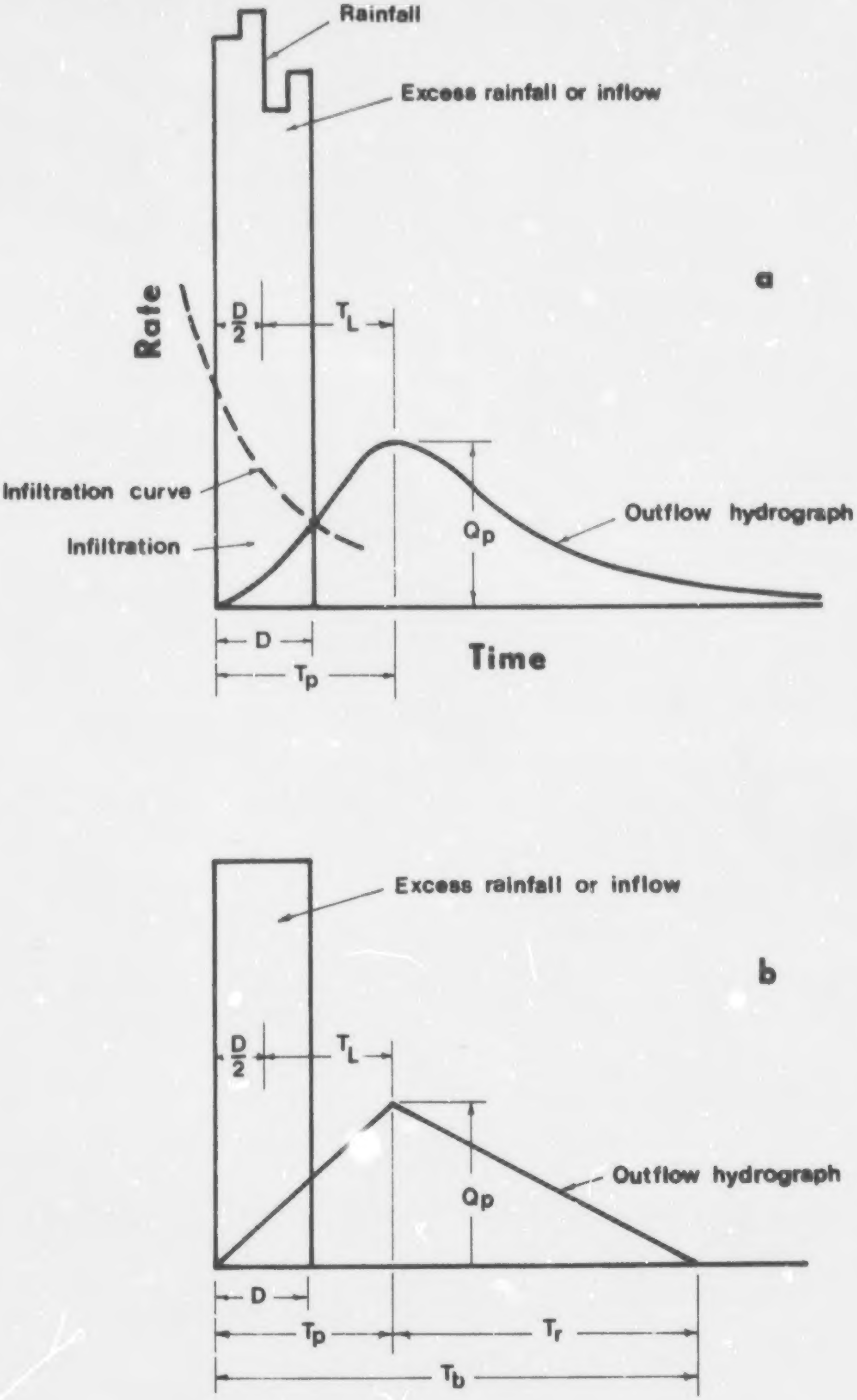
Rainfall
Excess rainfall or inflow
a
Rate
D/2
T_L
Infiltration curve
Infiltration
Q_p
Outflow hydrograph
D
T_p
Time
Excess rainfall or inflow
b
D/2
T_L
Q_p
Outflow hydrograph
D
T_p
T_r
T_b

Fig. 2

DEVELOPMENT OF TRIANGULAR HYDROGRAPH

deposition in reservoirs. This situation is accelerated by improper management of the land, which is due in part to a lack of understanding of the erosion process. Progress towards this understanding has been due to the difficulties in measuring sediment in motion which is reflected by a shortage of reliable records. This section will discuss first, a procedure for predicting annual sediment yield from climate and topography, and second, a means for estimating loss of soil by erosion from an individual storm.

Annual sediment yield

Statistical analyses have been made attempting to relate climatic and topographic variables to annual sediment yield. A study of watersheds in the more arid regions of the western United States was made by the U.S. Soil Conservation Service to determine if a few watershed variables could describe the variation and influence of changes in land use and treatment on sediment yield. The results of the analysis indicated that four watershed characteristics could be used to estimate sediment yield. These variables are

(1) climate or P/T ratio in which average annual precipitation is divided by average annual temperature.
(2) watershed slope as determined from topographic maps.
(3) the percent of soil particles coarser than 1 mm in the surface 50 mm of the soil profiles, and
(4) an indication of the aggregation or dispersion charactersitics of clay-size particles.

Another approach to determining sediment yield has been to use the Universal Soil Loss Equation which estimates annual soil loss together with a delivery ratio, the sediment yield at any point along a channel divided by the loss of soil by erosion above that point. The Universal Equation, described in more detail in the next section, is used to determine the erosion loss while delivery ratios are determined experimentally.

Sediment yield from storms

The Universal Soil Loss Equation has been modified to compute the sediment yield for individual storms on watersheds.

The Universal Equation is

$$A = R \times K \times LS \times C \times P$$

where A = computed soil loss per unit area
R = rainfall factor
K = soil-erodability factor
LS = slope length and gradient factor
C = cropping management factor
P = erosion control practice factor

The equation for estimating sediment yield from storms is

$$S = 95(q_p \times Q)^{0.56} \times K \times C \times P \times LS$$

where S = sediment yield in tons
q_p = peak flow rate in cubic feet per second
Q = volume of runoff in acre-feet

A delivery ratio is not needed as it is built into the above equation.

LITERATURE

Flaxman E. M. 1972. Predicting sediment yield in western United States. Journal Hydraulics Div. ASCE 98 (HY 12): 2073-2085.

Fogel, M. M. 1969. The effect of storm variability on runoff from small semi-arid watersheds. Transactions ASAE 12(6): 808-812.

Kent, K. M. 1968. A method for estimating volume and rate of runoff in small watersheds. USDA SCS-TP-149. 40 pp.

Soil Conservation Service. 1972. National Engineering Handbook. Section 4 Hydrology. U.S. Department of Agriculture. Washington, D. C.

Williams, J. R. and R. W. Hann, Jr. 1973. Hymo: Problem-oriented computer language for hydrologic modeling. Agricultural Research Service, U.S. Department of Agriculture ARS-S-9. 76 pp.

DESIGN OF SMALL WATER STORAGE AND EROSION CONTROL DAMS

A. D. Wood[1]
and
E. V. Richardson[2]

SMALL WATER STORAGES

Introduction

Although we hear most often about the large dams and reservoirs on major tributaries, farm ponds can be one of the most effective and useful structures in soil and water conservation.

Uses of Small Water Storages. Whether constructed on a hillside as a by-pass pond, or across a gully, an earth embankment can serve as an erosion control by decreasing flow velocities through a watershed and, thus, decrease sediment movement. A large portion of any sediment of load that does occur, can be trapped by the pond and prevented from causing damage downstream. Similarly, an embankment, when designed with some storage capacity, can retard flooding downstream during peak flows.

As a result of this conservation of water, a properly designed embankment can provide a usable supply of water. With appropriate outlet works or water lifting devices, water can be utilized for irrigation, stock watering, and fire protection (Figure 1). However, especially when used for irrigation, the storage capacity should be carefully planned and regulated to prevent severe drawdowns.

An additional benefit of creating a pond is the recreational possibilities; from swimming to fishing. If fish production is to be considered,

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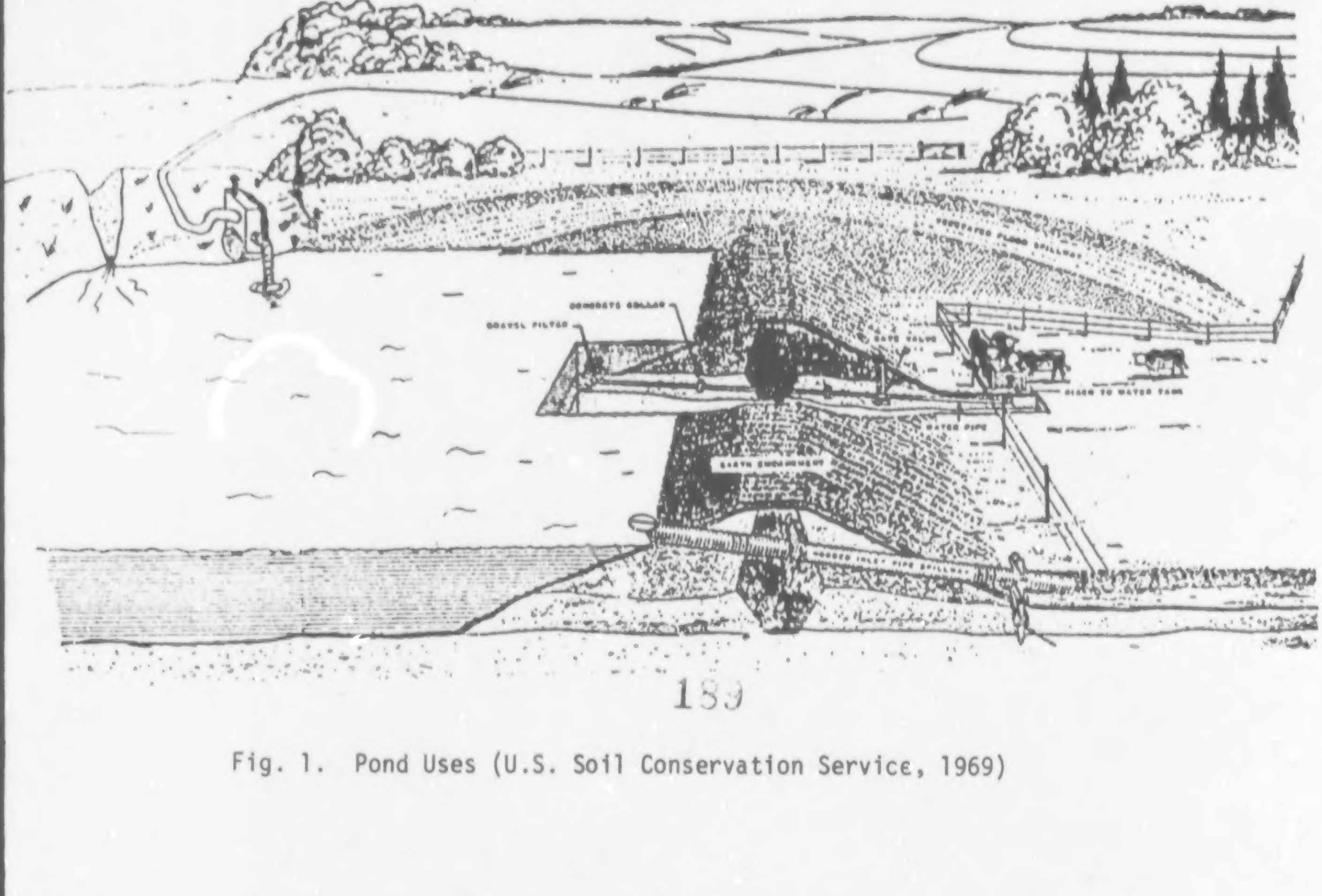

VEGETATED FLOOD SPILLWAY
CONCRETE COLLAR
GRAVEL FILTER
GATE VALVE
PIPE TO WATER TANK
WATER PIPE
EARTH EMBANKMENT
HOODED INLET PIPE SPILLWAY

Fig. 1. Pond Uses (U.S. Soil Conservation Service, 1969)

the pond should be designed no smaller than one-fourth acre surface area with a six foot average depth.

Types of small water storages. Although pond designs vary with location each is basically one of three types. The pit or dugout pond is developed by enlarging an already existing depression or simply by excavating a pit in flat land areas (Figure 2). The sources of water can be springs, underground seepage, or tile lines. Runoff should only be expected to contribute a small amount of the total supply. If existing depressions are normally wet, such as swamps, an impervious subsoil can be expected which will provide good water retention. However, if the depression appears well drained, another site should be selected, unless a lining (such as asphalt or clay layer) is to be considered.

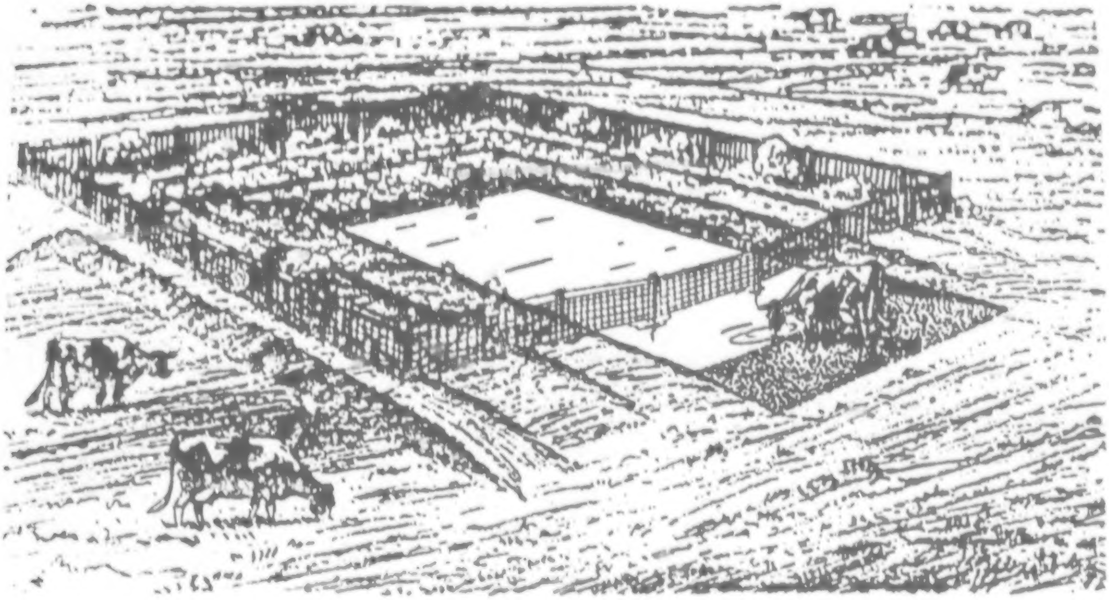


Fig. 2. Pit Pond (U.S. Soil Conservation Service, 1969)

The second and most widely used type is the embankment pond. Concrete, timber, and steel dams are forms of embankment, but are rarely considered for ponds due to high costs. An earth and/or rock filled embankment is generally the easiest and least expensive ponding method for the amount of water stored and materials moved. Where the foundation soil and the embankment material are sufficiently impervious to provide an adequate water barrier (as with silts and clays), the embankment is constructed entirely of this one material. This is a homogeneous type of embankment (Figure 3a). To provide sliding resistance along the foundation and prevent piping, the homogeneous fill is keyed into the foundation stratum by means of a key trench excavated the length of the embankment. If available fill material is not sufficiently impervious to retard seepage, a zoned embankment must be designed. In this type, the major portion of the embankment is pervious material and a water barrier is constructed. This barrier can be in the form of an internal core (Figure 3b) or diaphragm (Figure 3d), or as an impervious blanket on the upstream slope (Figure 3c). The commonly referred to rock fill dam is nothing more than a zoned embankment with very large, pervious material. The details and variations of these embankments will be discussed later.

The third kind of pond is actually a combination of the dugout and embankment ponds. It is often called a hillside or by-pass pond. It is designed when the dam cannot be placed across a gully or stream, due possibly to property lines or water rights. It is constructed on sloping land by excavating the uphill pond area and placing the cut material on the downhill side to form the embankment. As shown in Figure 4, discharge into the pond can be regulated by means of an upstream diversion. This method of water storage is also used frequently to retain farmlot wastes and function as a sewage lagoon. With good planning and proper design, these basic water storage structures can be adapted to most locations.

Factors governing selection of site, type, and capacity

Purpose. As with most engineering structures, several designs may be possible for a particular site. However, when the intended use of the pond

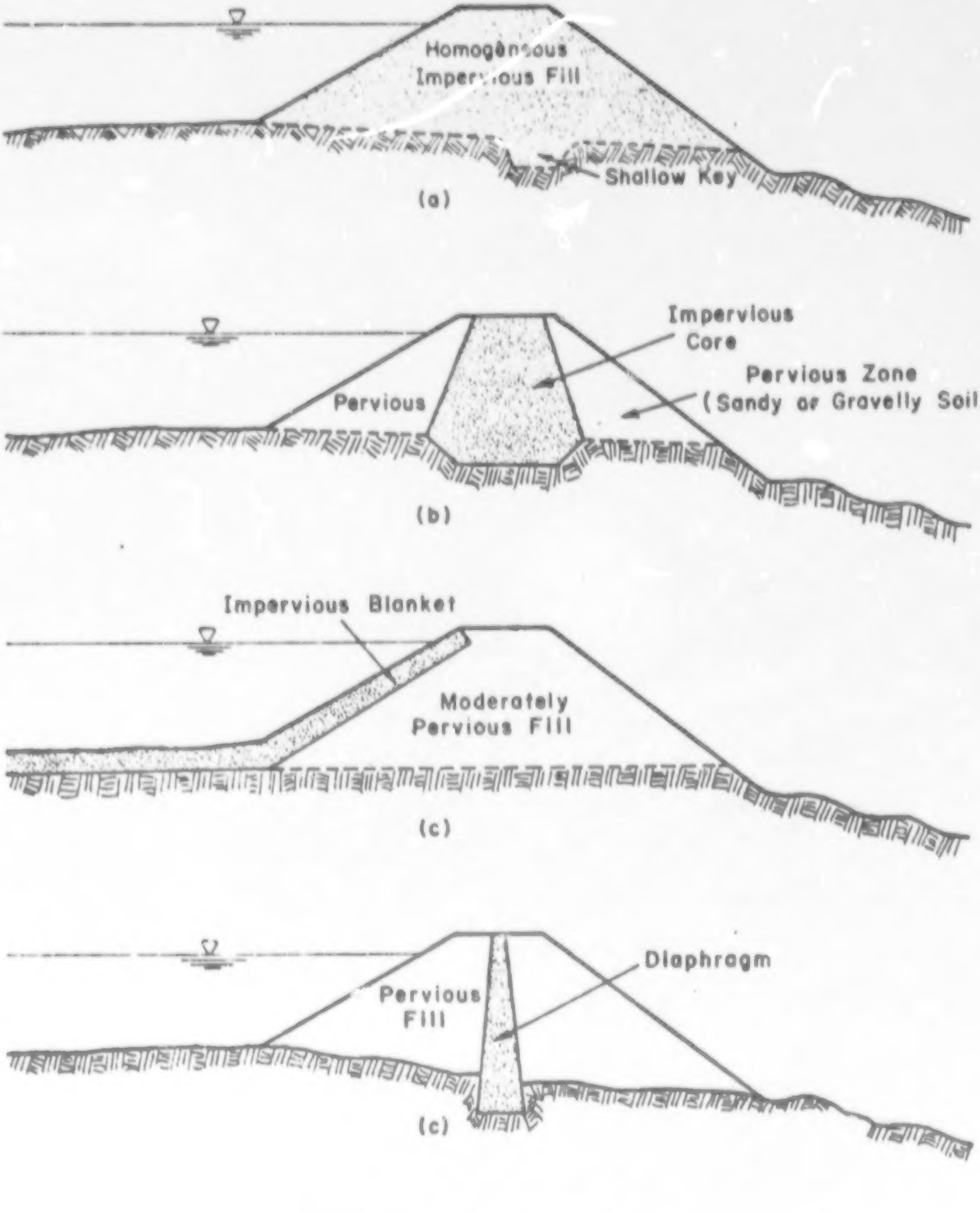

Homogeneous Impervious Fill
Shallow Key
(a)
Impervious Core
Pervious
Pervious Zone (Sandy or Gravelly Soil)
(b)
Impervious Blanket
Moderately Pervious Fill
(c)
Pervious Fill
Diaphragm
(c)

Fig. 3. Types of Embankments

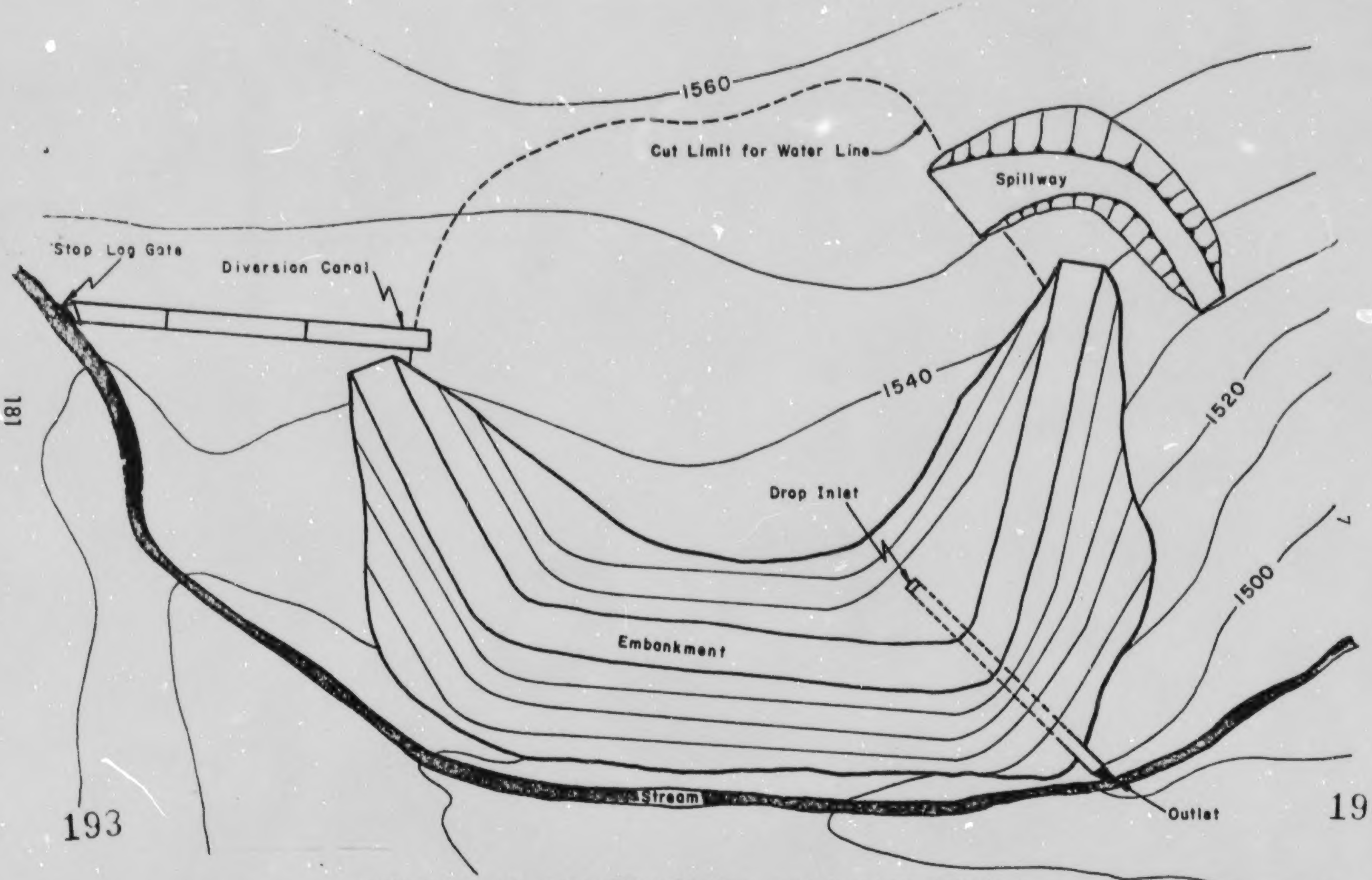

1560
Cut Limit for Water Line
Spillway
Stop Log Gate
Diversion Canal
1540
1520
Drop Inlet
1500
Embankment
Stream
Outlet

FIGURE 4 – HILLSIDE POND (Bypass with Diversion Canal)

is considered along with the site characteristics, an optimum design can be developed. For example, if the pond is to be used for irrigation, it should be located as centrally as possible to all fields to prevent excessively long reaches of pipes or canals. The location should also afford adequate storage capacity and low seepage losses. However, if the structure is primarily for flood and erosion control, the site should allow maximum runoff interception and the embankment material can be more pervious. When rapid drawdown is expected due to irrigation or stock watering, a zoned embankment with good upstream slope protection would be preferable to a homogeneous dam with only vegetation cover.

Topography. Topography, to a large degree, influences the site, type, and capacity of pond. For an embankment type pond, some desirable site characteristics are:

1. Narrow valley at damsite to reduce fill and provide deep water storage which reduces evaporation losses.
2. Wide abutments for an emergency spillway with minimum excavation.
3. An alternate water course to allow diversion during construction.
4. A flat valley slope upstream to minimize deep cuts in the pond area.

Where the topography is nearly level, a dugout pond is more suitable. However, the site should have a high water table to prevent seepage loss and an adequate drainage area or aquifer supply to keep the pond full.

To insure that the water storage capacity at a selected site will be adequate for the intended use, an estimate of capacity should be made. For an embankment pond, a reasonable estimate can be made by multiplying the proposed surface area by 0.4 times the maximum water depth at the dam. For a dugout pond, the capacity will simply be the volume of proposed excavation.

Topographical maps, visual inspections, and preliminary surveys are valuable guides to site selections.

Subsurface investigation. After a pond site has been located which is suitable for the topography and intended use, the local subsurface should be investigated to determine the quality of the foundation strata and the classification of available borrow soil for the embankment fill. To obtain this information, boring and/or test pits should be extended to stable and relatively impervious material. Figures A1 and A5 in the appendix give a classification and values of permeability as a function of particle size. As a rule, if such material is very deep, investigation to a depth equal the dam height is sufficient. Mobile drills or back hoes are best suited for such exploration, but for small ponds, hand augers or posthole diggers are adequate. Areas to be investigated, as shown in Figure 5, are:

1. Along the embankment centerline, continuing up abutments.
2. Various points in the pond and borrow areas.
2. Along the centerline of the emergency spillway.
4. Any points where footings will be constructed, e.g., at drop inlet.

Soils in the ponded area should contain layers of materials that are relatively impervious and thick enough to prevent high seepage losses. Natural layers of clays and silts are good materials, while sands and gravels should be avoided. However, ponding can be accomplished on sands or silty sands if the water table is high enough or if sealing or lining can be afforded. Sites where faults or limestone sinks and caverns are present should also be avoided without extensive investigations and laboratory tests. Sites in earthquake areas deserve special design considerations and will be discussed later.

The soil profile beneath the embankment and at footings must provide stable support for all conditions of saturation and loading in addition to being relatively impervious. Foundation soil of low shear strength will require a flatter sloped and broader dam. A more liberal allowance for embankment settlement must be allowed for soft foundation material. If the foundation material is pervious, a seepage cutoff trench or impervious blanket will be needed. Rock foundations are excellent for bearing strength, but often require grouting to seal fractures to control seepage. Springs in or near the embankment can cause serious piping and should be avoided.

Borings in the emergency spillway site should be made to a depth at least one foot below the spillway's finished grade. The soil should be classified and the compaction and plastic qualities determined in order to design for maximum velocities in the spillway.

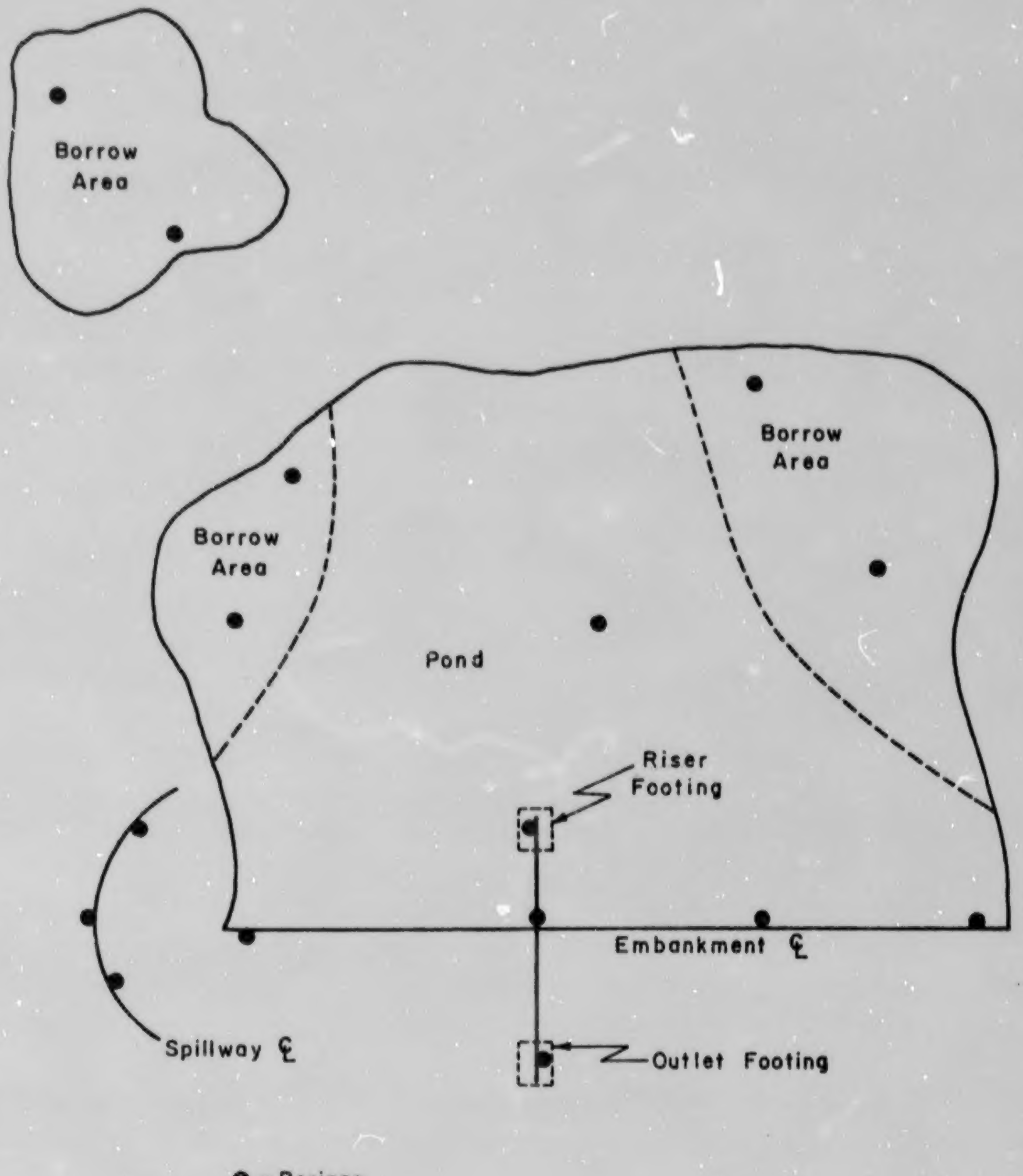

Borrow Area
Borrow Area
Borrow Area
Pond
Riser Footing
Embankment ℄
Spillway ℄
Outlet Footing
● — Borings

Fig. 5. Borings at Proposed Site

The type of material which will be available from excavations and borrow areas must be evaluated for bearing strength and permeability to determine if the embankment will need an impervious core or blanket, optimum moisture, and the degree of compaction that can be achieved. If borrow material is not available at a reasonable distance from the project, it should be determined if enough cut material can be obtained from the pond and spillway areas to construct the embankment.

Sites proposed for dugout ponds also require a thorough subsurface investigation to insure that the soil layer at the designed depth is relatively impervious. If the pit pond is to store water from an aquifer, test holes should be made to determine the level to which the water will rise. When this level is more than six feet below existing ground level, the site will not be economical to construct unless another water source can be utilized.

Methods of subsurface testing and the evaluation of collected samples and data can be obtained from most soil manuals, soil text books, or field handbooks from such organizations as the U.S. Soil Conservation Service, or the Mexican Secretary of Hydraulic Resources (Secretaria de Recursos Hidraulices).

Climate. Climate is an important consideration at a proposed pond site. Not only must it be considered for hydrological design data, but is of critical concern during construction. The estimated mean and peak runoff discharges, as discussed in previous presentations, are the primary input for spillway capacities. Evaporation, which is a function of climatic conditions, must be considered along with seepage in determing the net loss of storage. Wind and temperature are factors that will be important in embankment freeboard design.

During construction, little work should be done on embankments of fine-grained soils in wet or freezing weather. Movement on wet or frozen silts and clays will destroy any compaction effort. However, placement of pervious soil or rock can be done during such wet or freezing periods. In rainy areas, to facilitate construction and provide drainage during operation, embankments would best be designed of pervious materials with an internal impervious zone. In arid areas, the lack of water may be a problem in maintaining optimum moisture for compaction. An adequate water supply should be available, either from the stream or some outside source and a continuous check made on the moisture content of fill material. When necessary, water must be sprayed on each fill layer before compaction, being careful not to puddle or over water.

In dry climates, it should be determined if vegetation can be maintained as slope portection or if an alternate cover will be necessary. This is a very important consideration, since a hard rain can easily destroy a bare earth structure.

Equipment and labor. The availability and use of construction equipment, either mechanical or manual, is a limiting factor in pond location and design. The basic operations which are needed for pond construction are excavation, hauling, spreading, and compaction. For small ponds, either dugout or embankment types, manual and animal labor can be especially well used. Steep, narrow valley sites also make machinery movement difficult and are better suited for manual labor. In such cases, the excavation can simply be done by pick and shovel, but an allowance for increased manpower will be necessary in hard clay and rocky soils.

Wheelbarrows can be used for hauling short distances; however, for leads of more than 180 meters the efficiency decreases and animal-drawn carts or scrapers should be used. Spreading the material can be done by shovel or an animal-drawn scraper or blade. Good compaction is difficult to achieve with manual labor, and thus the design should allow for more seepage and greater settlement. Spreading thin layers of fill (i.e., 3-4 in.), hand tamping, utilizing maximum cart traffic, and possibly even herding livestock across the embankment will aid in compaction. Special care in tamping must be used around spillways, outlets, and abutments to insure good compaction.

If the soil to be excavated is not excessively hard or rocky, one or two farm tractors and a few accessories can be sufficient to build a pond. With a plow to loosen soil and a front-end loader or drawn scraper to excavate, a pond can be constructed quite inexpensively. If an embankment pond is to be built, a wagon for hauling and a water-filled roller for compaction may also be needed.

If heavy equipment is available or the pond is quite large, several combinations of machinery can be used and will produce a strong structure in a relatively short time. A single bulldozer can normally excavate and spread the cut material for a fair size dugout pond (approximately 1/2 acre) in a single day. Most small embankment ponds can be built with a bulldozer and a sheepsfoot or rubber-tire roller. If the pond area is large or fill must come from a borrow area, a towed or self-propelled pan, or a truck should assist in hauling. As embankment size increases, more equipment may be necessary to improve construction economy.

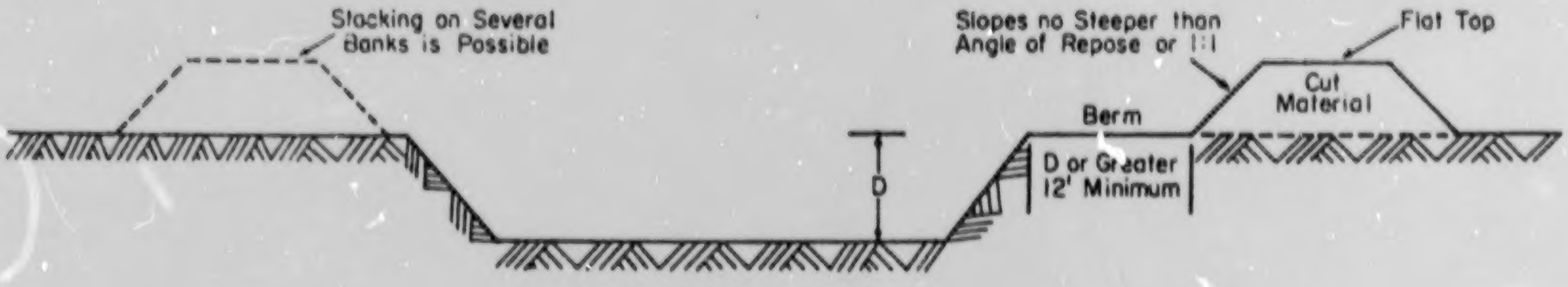
No matter which level of equipment is used, some means of applying water to aid compaction should be available, and hand or pneumatic tamping should be done at spillways, outlets, and abutments.

Statutory restrictions, costs, and time. Before spending any time or money on site investigations or designs, any legal regulations governing water rights and ponding structures should be considered. Restrictions are often made on the distance from impounded water to roadways or buildings and on factors of safety in design specifications. Property lines and water rights may limit the pond location and amount of water storage.

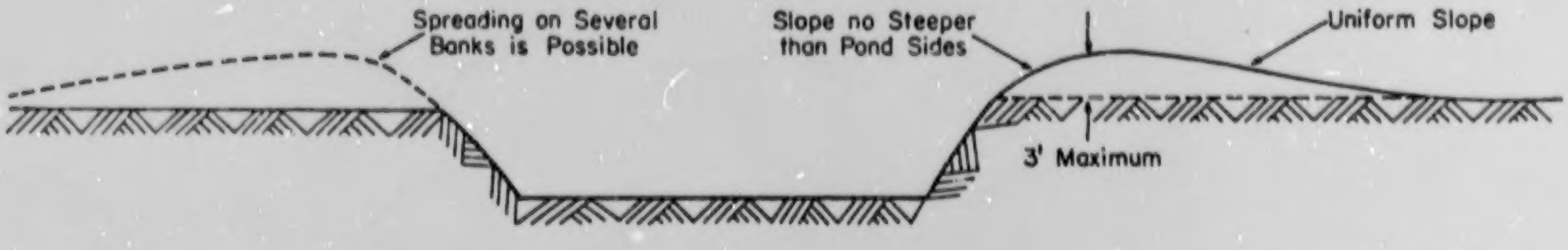
Because of widely fluctuating economic and labor conditions in different localities, it is not possible to consider costs in this presentation. However, the amount of time and money spent in pond construction should always be weighed against the value of the pond's uses.

Design of small water storages

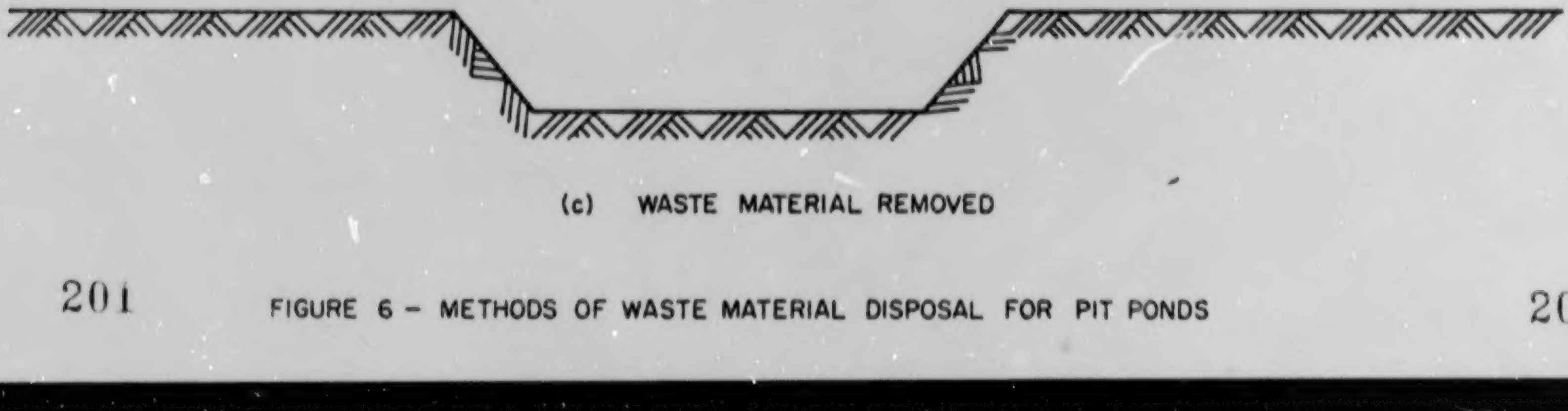
Dugout ponds. Dugout ponds are the simplest type to construct and, thus, require only a few design considerations. The shape can be made to fit any location. However, a rectangular shape is the most convenient to excavate if machinery is used. For a pond fed by aquifers, the design area will depend on the capacity desired and the depth of the aquifers. However, since aquifer inflow may be altered by the construction, additional area


Stacking on Several Banks is Possible
Slopes no Steeper than Angle of Repose or 1:1
Flat Top
Cut Material
Berm
D
D or Greater 12' Minimum

(a) WASTE MATERIAL STACKED


Spreading on Several Banks is Possible
Slope no Steeper than Pond Sides
Uniform Slope
3' Maximum

(b) WASTE MATERIAL SPREAD



(c) WASTE MATERIAL REMOVED

FIGURE 6 - METHODS OF WASTE MATERIAL DISPOSAL FOR PIT PONDS

should be available for pond enlargement if the original design proves inadequate. For a dugout pond fed by runoff or diverted streamflow, any combination of area and depth can be designed which yields the desired storage volume. For example, if approximately 0.25 acre-feet (or 82,000 gallons) of water are needed for stock watering and a permanent storage of 0.75 acre-feet allowed for fire protection, any dimensions which provide one acre-foot of volume will be adequate. However, it should be remembered that the greater the surface area, the greater the evaporation and seepage. Thus, a 0.25 acre area with a four-foot depth would be a reasonable design. The side slopes should not be steeper than the natural angle of repose of the soil or 1:1. If livestock will be allowed to water directly from the pond, at least one side should have a slope of 4:1 or flatter and be protected with a paved, rock, or timber surface as in Figure 2.

The placement of excavated material must be included in the design. It can be stacked or spread at the pond site, or removed altogether. If stacked (Figure 6a), the embankment should have flat enough sides to prevent soil erosion back into the pond. A berm, the width of the pond's depth, or at least 12 feet, should also be allowed to insure stability of the pond's sides. Embankments placed on the windward side of the pond can reduce evaporation. Spreading the cut material along one or more sides has several advantages; decreased pressure on pond sides, protection against overflow, and ease of establishing vegetation cover. The height of spread material should not exceed three feet and the slopes graded quite flat (Figure 6b).

Embankments and foundations. The major design consideration for embankment type ponds is the dam cross section, while the pond area is almost predesigned.

The pond area is determined by trial and error. The desired storage volume will be produced by a best-fitting dam height and corresponding area within the waterline elevation contour. As previously mentioned, a good estimate of storage volume is 0.4 times the dam height, times the pond area. Thus, as illustrated in Figure 7, set a trial dam elevation and see if the area circumscribed by the contour at that elevation will fit this estimate.

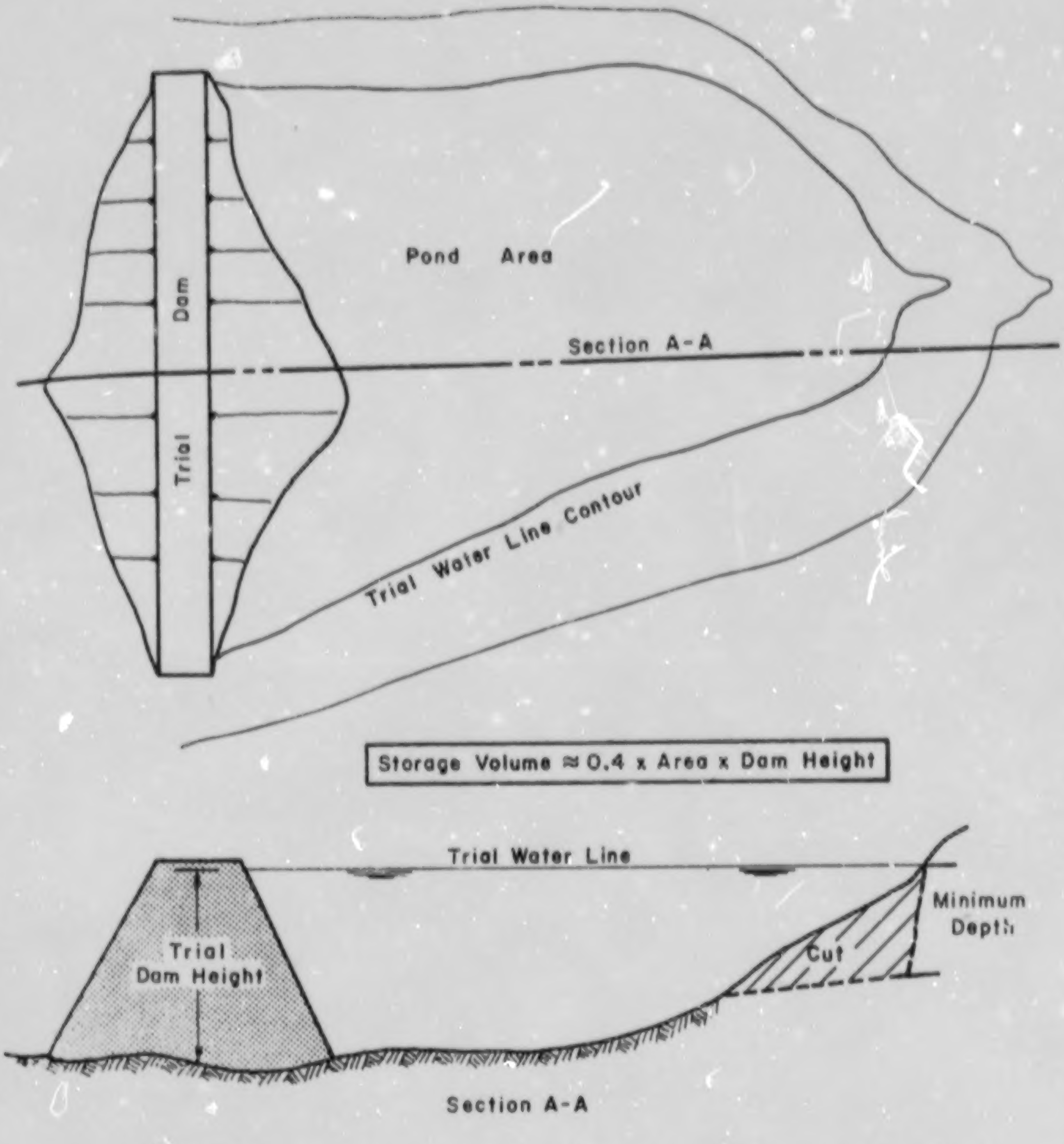

Pond Area
Trial Dam
Section A-A
Trial Water Line Contour
Storage Volume ≈ 0.4 x Area x Dam Height
Trial Water Line
Trial Dam Height
Minimum Depth
Cut
Section A-A

Fig. 7. Estimating Storage Volume

If the estimate is reasonable, determine the amount of cut necessary to provide the desired minimum pond depth. Then compute the actual volume that will result. If this trial does not give a tolerable result, adjust the dam elevation accordingly. Also, determine if the useable cut material is sufficient to construct the embankment. If more fill is needed, it can be obtained by deepening the pond or obtaining a borrow area. Deepening the pond should be considered first to hold down costs. The additional volume will also increase the sediment trap efficiency.

In the process of determining the needed pond area, the required dam height has also been obtained. However, to provide a factor of safety against overtopping, a freeboard must be added to the normal waterline elevation (Figure 8). Of primary importance is the flood storage free board. This is the elevation difference between the outlet works crest and the emergency spillway control section. To avoid calculating flood routing data for the watershed of a small pond, graphical guides, such as Figure 9, can be used to estimate the flood storage based on peak runoff and pond area. The depth of flood flow in the emergency spillway must also be added to the freeboard. (This design depth will be determined later.) An allowance should also be made for wave action and frost penetration. For ponds, wave height can be estimated by Hawksley's formula: $h = 0.025\ (f)^{\frac{1}{2}}$, where h is the wave height and f the fetch in feet. The amount of freeboard to allow for loosening of soil by freezing and thawing can be obtained from local frost penetration records. Additional freeboard should be added for safety if valuable property would be damaged by an embankment failure.

Another addition to the constructed dam height must be an allowance for settlement. This can accurately be determined by considering void ratios for the fill material. However, a good rule for small ponds is to increase the dam height by 10 percent at each point since small dams do not usually receive adequate compaction.

Once the dam height has been determined, the top width and side slopes can be designed. On embankments less than 50 feet high (which usually includes farm ponds), slopes should not be steeper than 3:1 on upstream faces and 2:1 on downstream faces for most materials. Well-graded soils, if well compacted, can tolerate 2:1 slopes on both faces, while course materials may

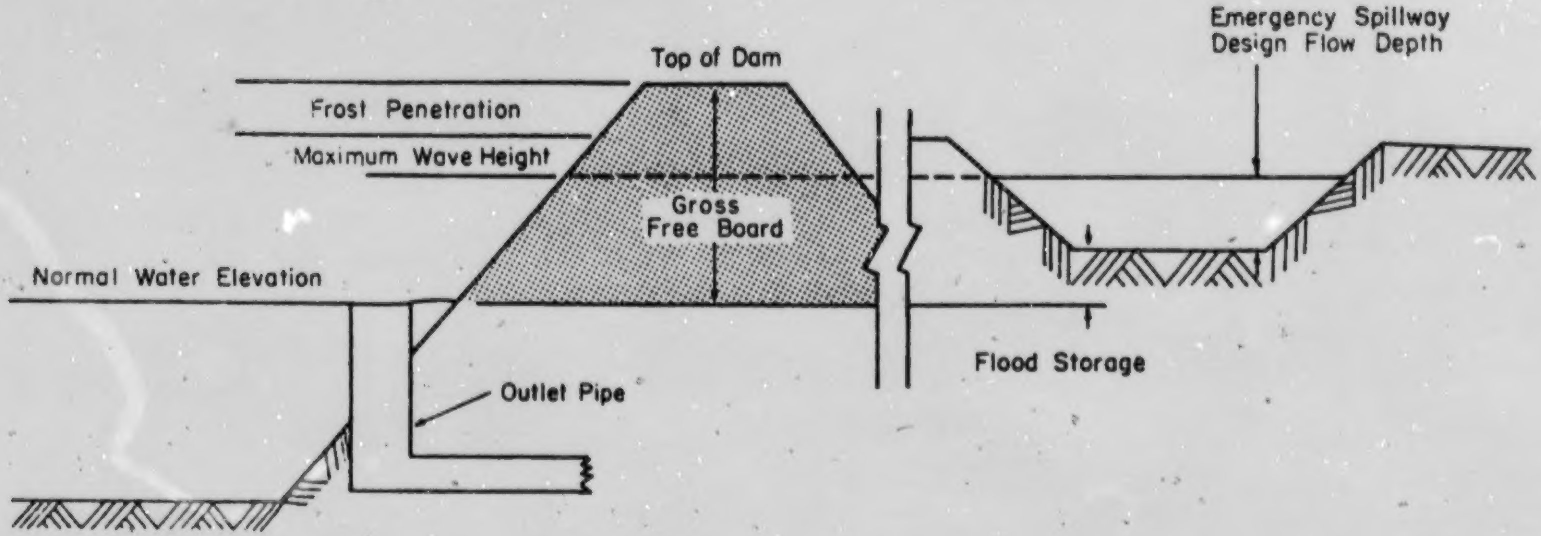

Emergency Spillway
Design Flow Depth
Top of Dam
Frost Penetration
Maximum Wave Height
Gross
Free Board
Normal Water Elevation
Flood Storage
Outlet Pipe

FIGURE 8 – DESIGN FACTORS OF FREEBOARD

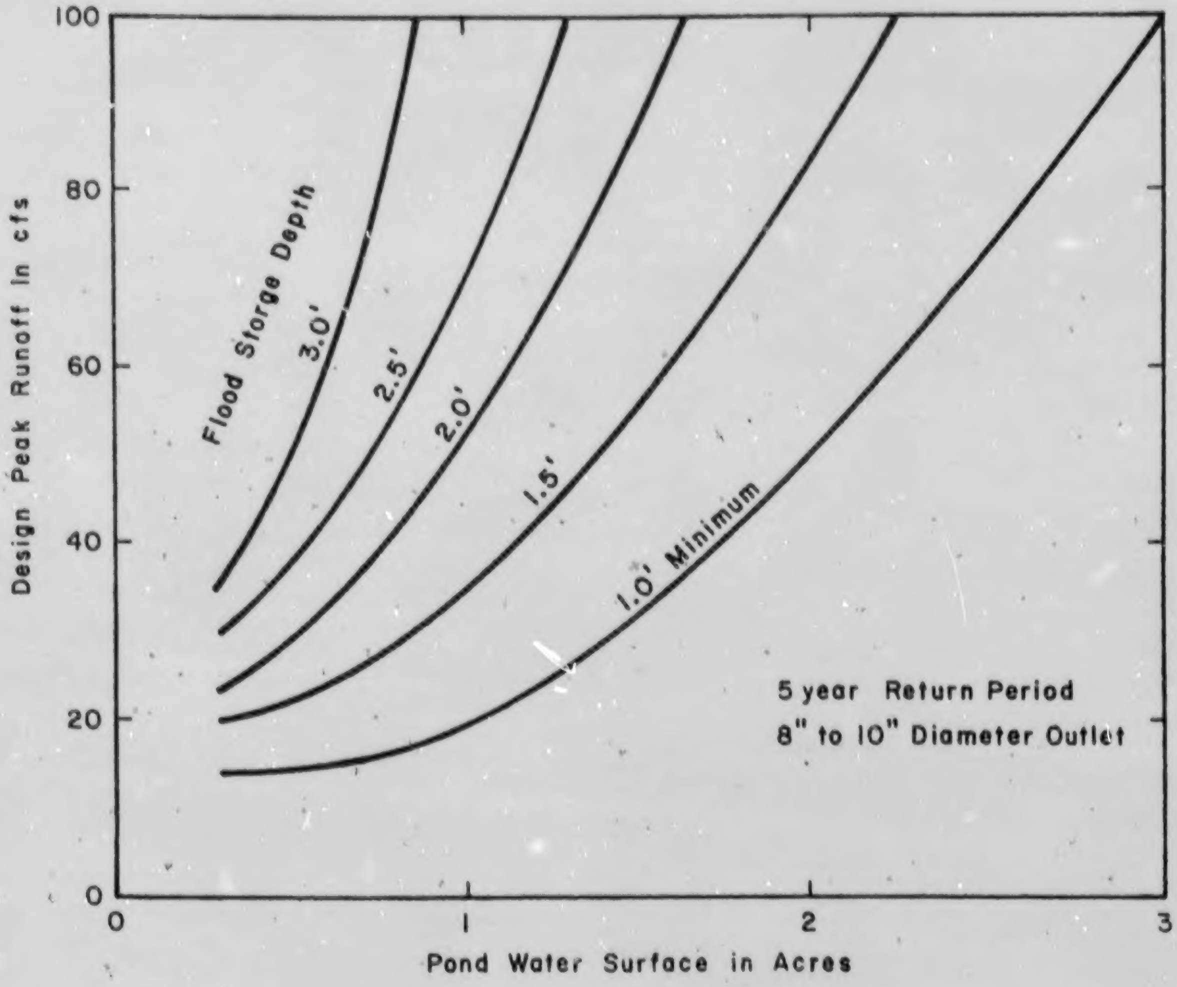


Fig. 9. Suggested Flood Storage Depth (Schwab, G. O. et al. Soil and Water Conservation Engineering)

require 4:1 sides. If machinery is used in construction, the minimum top width must be the width of the placing and compacting equipment. However, an embankment less than 15 feet high should have at least a seven-foot top width. Higher embankments should use the guideline that the crest width should equal one-fifth the maximum dam height plus 10 feet.

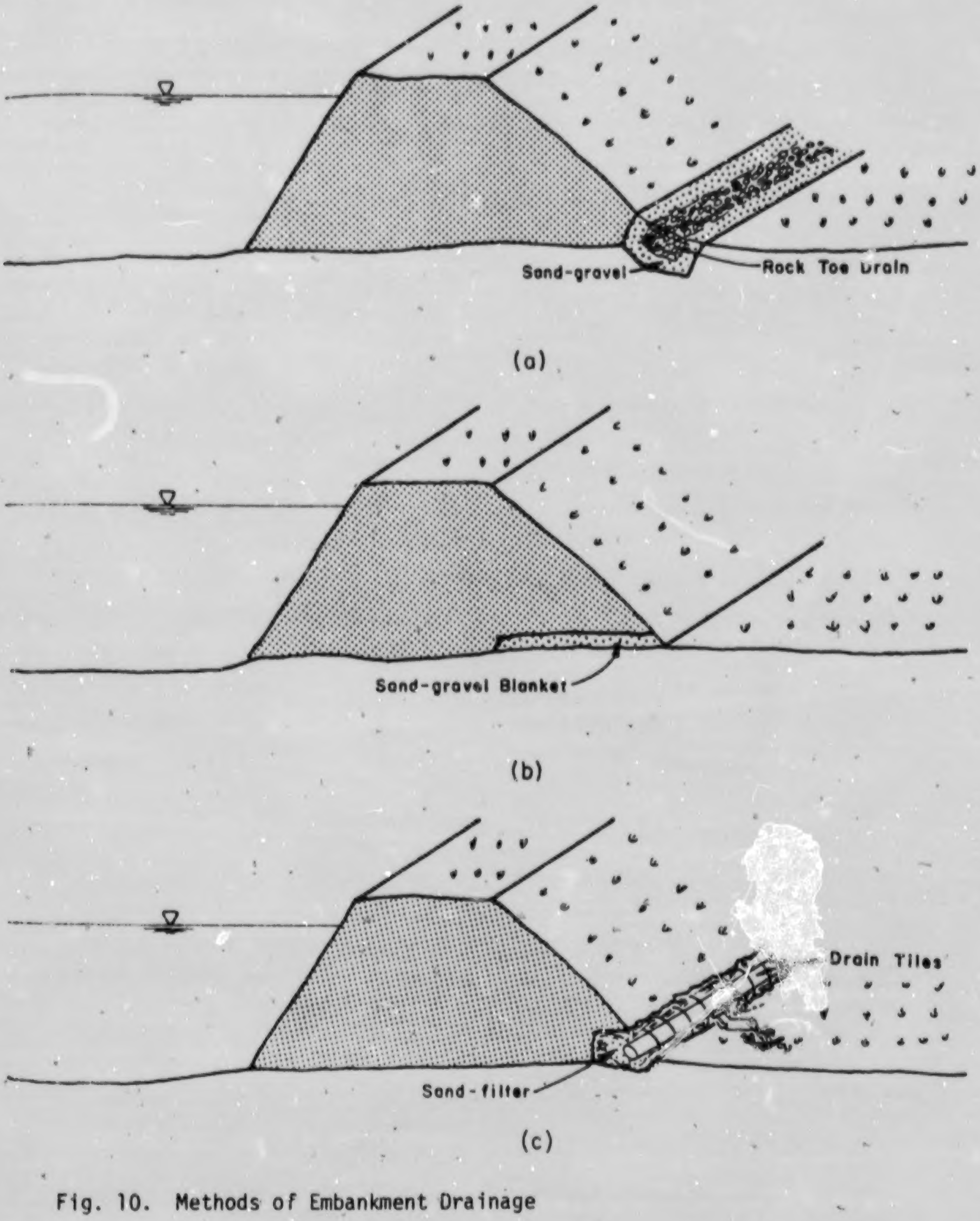

Sand-gravel
Rock Toe Drain
(a)
Sand-gravel Blanket
(b)
Drain Tiles
Sand-filter
(c)

Fig. 10. Methods of Embankment Drainage

It should be noted that if the pond site is in an area of frequent earthquake activity, flatter side slopes near the dam crest and a small additional freeboard should be designed to improve stability and increase the factor of safety.

With the information obtained from the subsurface investigations and having determined the dam height, a design can be developed for the dam cross section. As previously discussed, fine-grained materials allow for a homogeneous cross section. However, a rock toe drain (Figure 10a) or pervious drainage blanket (Figure 10b) should be included at the downstream toe to prevent piping. This is done by placing rock and/or a sand and gravel filter along the toe for the first several layers of fill. If rock or gravel is not readily available or more drainage is thought necessary, tile drain pipe may be installed within a sand filter in the lower downstream third of the embankment (Figure 10c).

If the embankment material is quite permeable, several combinations of impervious cores, diaphragms, and blankets can be designed to reduce seepage through the dam. However, for small ponds, an internal core of well-compacted clay is usually the easiest and most economical to construct (Figure 3b). At the foundation elevation, the core should account for the inside one-third of the dam thickness along the entire dam length. The core should have side slopes of 1:1 or steeper, but at least sufficient to extend the core to the embankment crest. If clay type material is not available, an internal diaphragm (Figure 3d) or upstream blanket (Figure 3c) of concrete or bituminous concrete can provide an adequate water barrier. However, diaphragms are susceptible to cracking from settlement and blankets are often undermined. They should be avoided when possible for small dams and carefully designed and constructed when necessary. A toe drain should also be included in the design of a zoned embankment.

The most satisfactory foundation for a dam is a thick layer of impervious material at or near the surface. To prevent slippage and seepage between such a foundation and the embankment fill, a shallow key trench should be designed (Figure 3a). It should be at least two or three feet deep and about 10 feet wide. For a zoned embankment with an impervious core, the key trench becomes a downward extension of the core (Figure 3b). If the

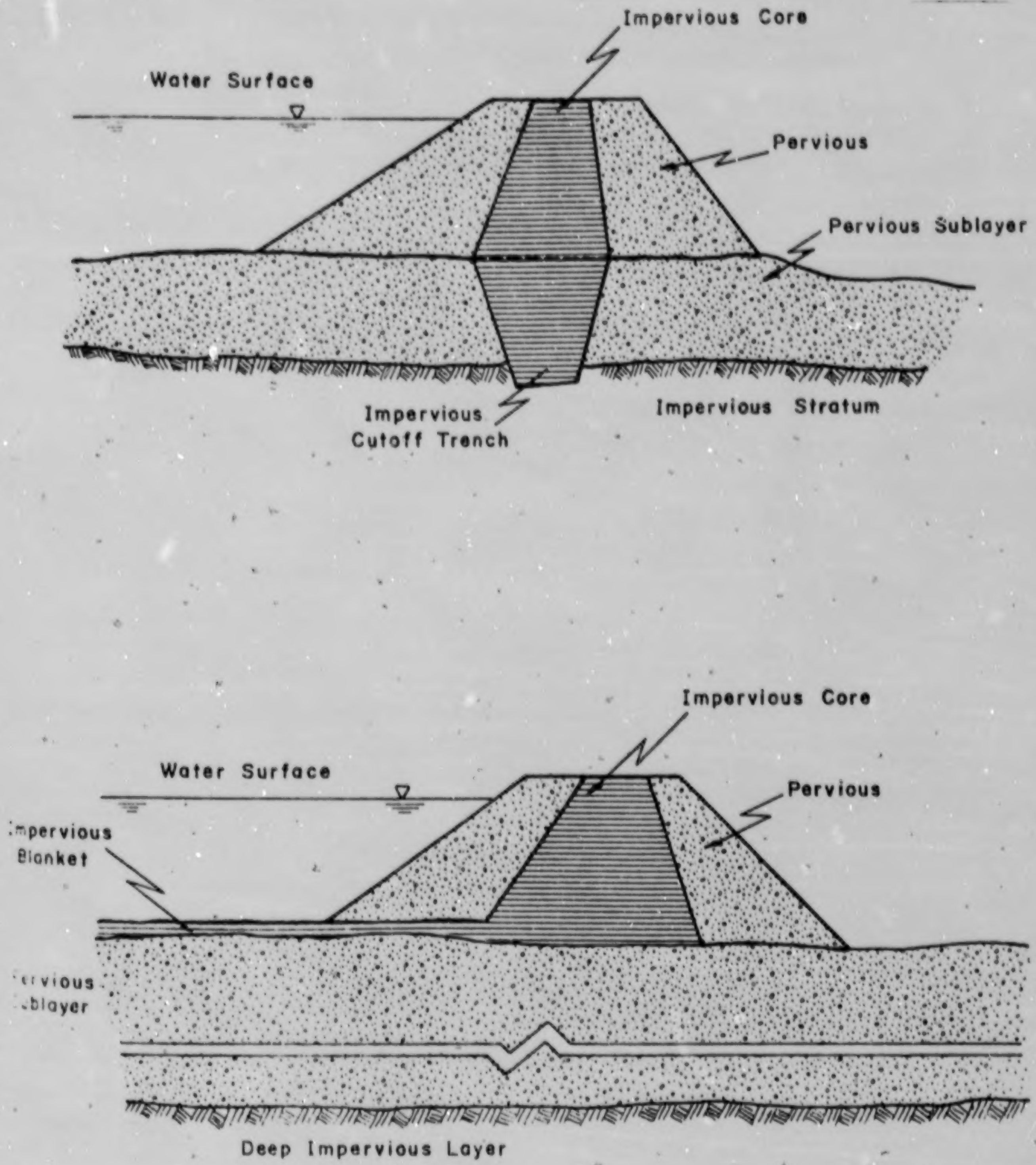

Impervious Core
Water Surface
Pervious
Pervious Sublayer
Impervious Cutoff Trench
Impervious Stratum
Impervious Core
Water Surface
Pervious
mpervious Blanket
rvious
blayer
Deep Impervious Layer

Fig. 11. Treatment of Pervious Foundations

foundation consists of permeable soil, with a rock or impervious stratum at a reasonable depth, the trench should be excavated down to that layer, as in Figure 11 . Such a cutoff trench is filled with impervious soil the entire embankment length and up the abutments. The cutoff should have a bottom width of at least four feet and with about 1:1 side slopes. If the impervious substratum is too deep to be reasonably reached, a blanket design might be utilized. For the previously mentioned reasons, an overlying blanket, as in Figure 3c, should be used with caution. However, a blanket extension of an internal core is a good design for deep, pervious foundations. This impervious blanket should be extended well upstream to prevent undermining (Figure 11b).

During the design stage of any earth embankment, the seepage under and through the dam should be estimated to check the size and location of water barriers and drains. A discussion of embankment seepage is given in Appendix A.

Some form of slope protection must be designed for the embankment to prevent erosion. For small ponds, the best cover is a good thick sod on the up and downstream faces and crest. If the top of the dam is to be used as a roadway or livestock crossing, the edges of the crest should be protected by fencing or rock to prevent damage. Where arid conditions prevent good vegetation or if severe drawdown is expected, a riprap cover can be used. A sand and gravel filter, one to two feet thick, should be provided beneath the riprap to keep the fine embankment material from washing out.

Outlet works. Most small ponds are protected from overtopping by a vegetated emergency spillway. However, to allow drawdown by gravity and to prevent the earth spillway from being continually wet, an outlet structure is usually provided. However, in arid regions, outlet structures are often not needed and the flood spillway or spreading ditches are used as outlets. The outlet structure is usually designed to carry the mean flow. However, if steep or soft abutments prohibit the safe use of an earth spillway to carry peak flows, the outlet works must be designed to carry both mean and flood flows. This can be done with a chute spillway or multi-stage inlet. A chute spillway (Figure 12) should only be constructed on an embankment of well-compacted soil with a high bearing strength. However, a multi-stage inlet, such as Figure 13, can be designed for any outlet works and provides for a flood storage capacity.

Outlet works must be constructed of durable material that will resist damage due to settling or moving loads. Several basic combinations of outlet structures are usable for pond dams; a concrete block or reinforced concrete inlet with a corrugated metal pipe or concrete pipe conduit (Figures 14 and 15), a hooded CMP conduit with no riser (Figure 16), or for larger ponds, a monolithic structure combining riser and barrel (Figure 17). However, the most popular outlet structure for small ponds is a CMP conduit passing through the embankment with a drop inlet of the same material (Figure 18). Such a structure is more durable than concrete, can be assembled off the project site and set in place in one operation at the proper fill elevation. For the construction of several small ponds, the design of these outlets can be standardized and mass assembled, saving time and money. As shown in Figures 18 and 19, this type outlet can easily be used with a valve or gate to allow drawdown for irrigation or other water uses. The inlet pipe to this valve or gate can also be used to divert runoff through the dam during construction.

To determine the size outlet works necessary to carry the design flow, it is best to consult design tables or graphs (Figures 20 and 21) which provide discharge capacities for various combinations of risers and barrels. Entering such figures with only the design flow, several usable pipe sizes and design heads will be suggested. This design head is the elevation difference between the inlet and the emergency spillway, as mentioned in the freeboard discussion. If such guidelines are not available, Bernoulli's principle and Manning's equation of flow may be utilized.

All conduits passing through the dam should be fitted with antiseep collars to prevent erosion of soil along the outside surface of the conduit. These collars can be metal, welded to the pipe, or concrete, poured in forms around the conduit after it is in place in the embankment. Two 2' X 2" collars are usually sufficient for small water pipes and two 4' X 4' collars will protect most outlet works (Figure 18). For large embankments, the number and size of collars should be large enough to increase the creep

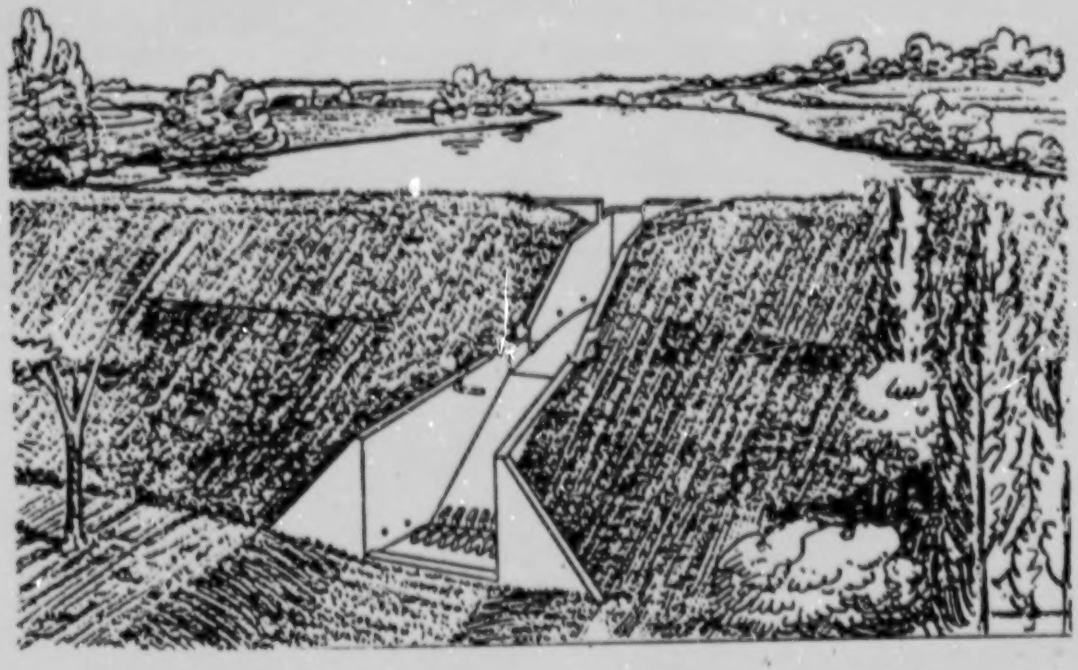


Fig. 12. Shute Spillway (U.S. Soil Conservation Service, 1969)

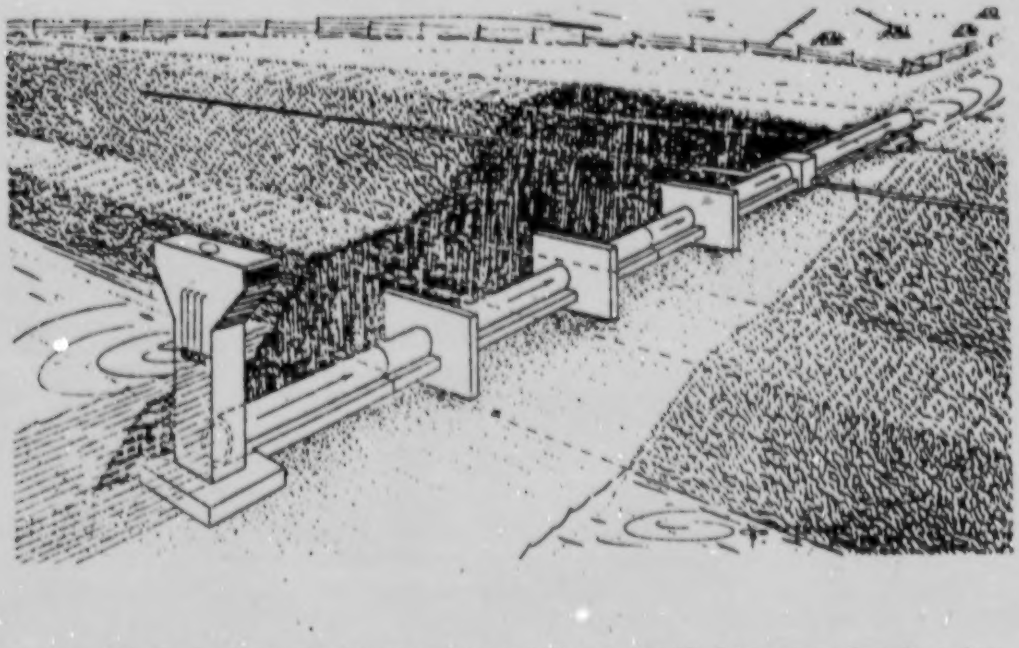


Fig. 13. Outlet with Multi-Stage Inlet (U.S. Soil Conservation Service, 1969)

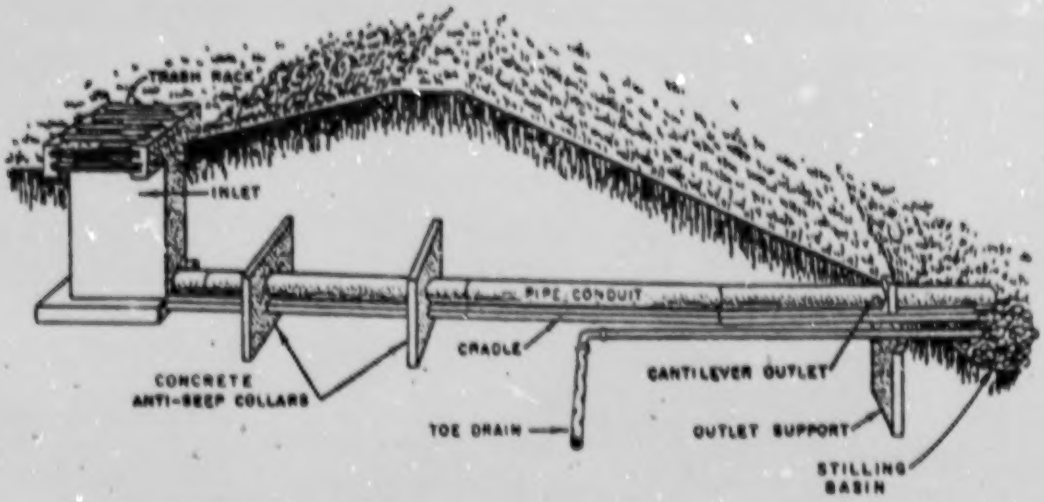

TRASH RACK
INLET
PIPE CONDUIT
CRADLE
CONCRETE ANTI-SEEP COLLARS
CANTILEVER OUTLET
TOE DRAIN
OUTLET SUPPORT
STILLING BASIN

Fig. 14. Reinforced Concrete Inlet and Pipe (U.S. Soil Conservation Service, 1969)

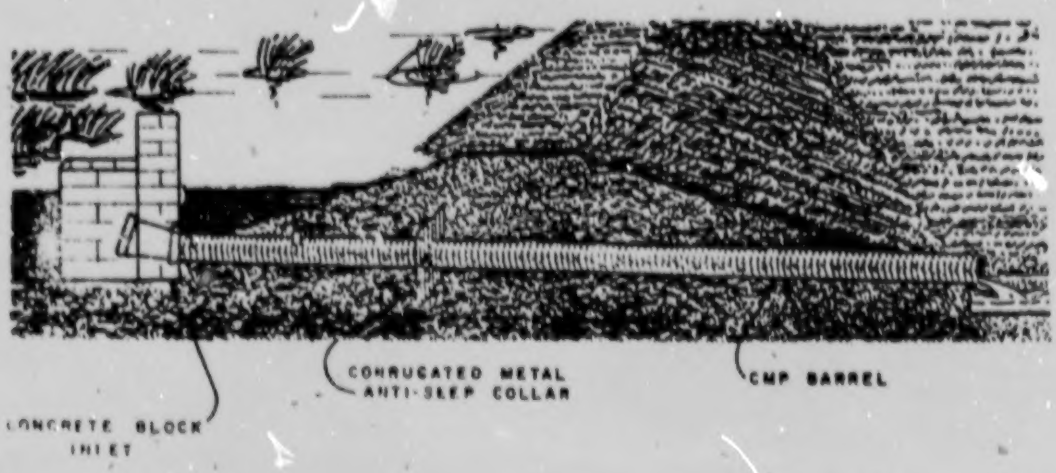

CORRUGATED METAL ANTI-SEEP COLLAR
CMP BARREL
CONCRETE BLOCK INLET

Fig. 15. Concrete Block Inlet with CMP Barrel

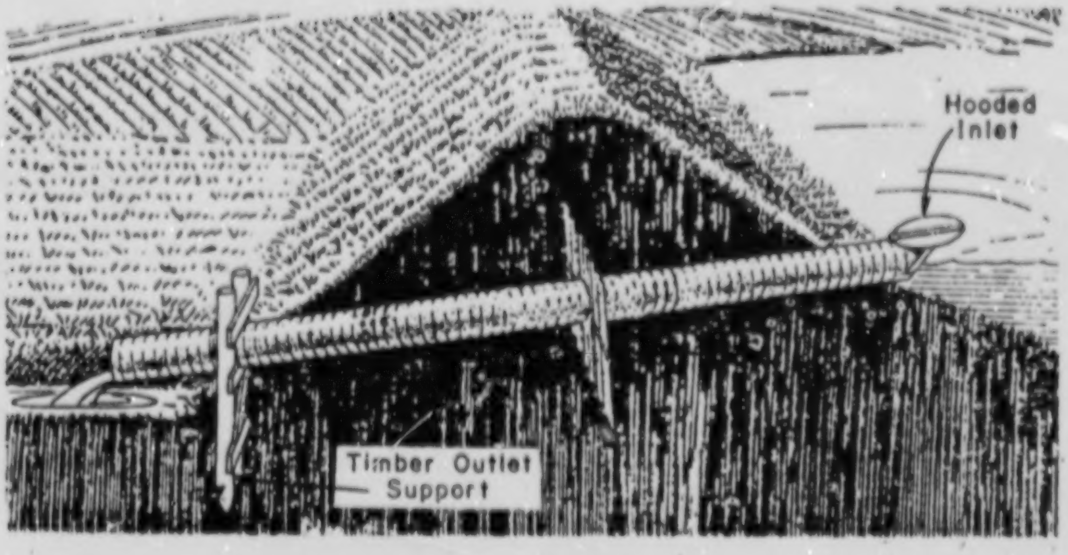

Hooded
Inlet
Timber Outlet
Support

Fig. 16. Hood CMP Outlet (U.S. Soil Conservation Service, 1969)

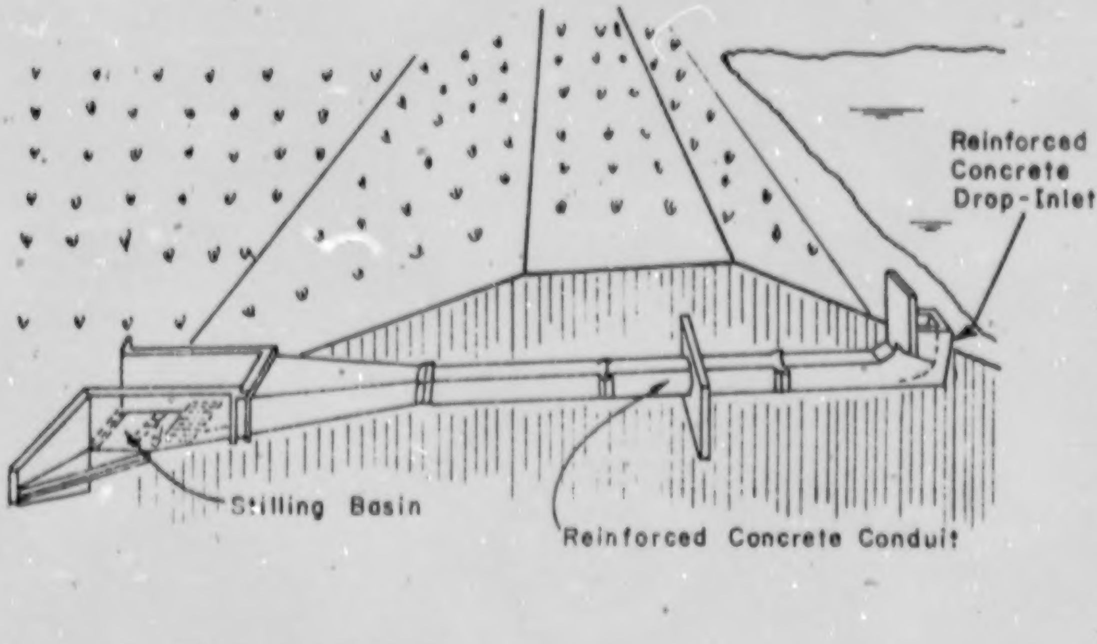

Reinforced
Concrete
Drop-Inlet
Stilling Basin
Reinforced Concrete Conduit

Fig. 17. Monolithic Outlet Works

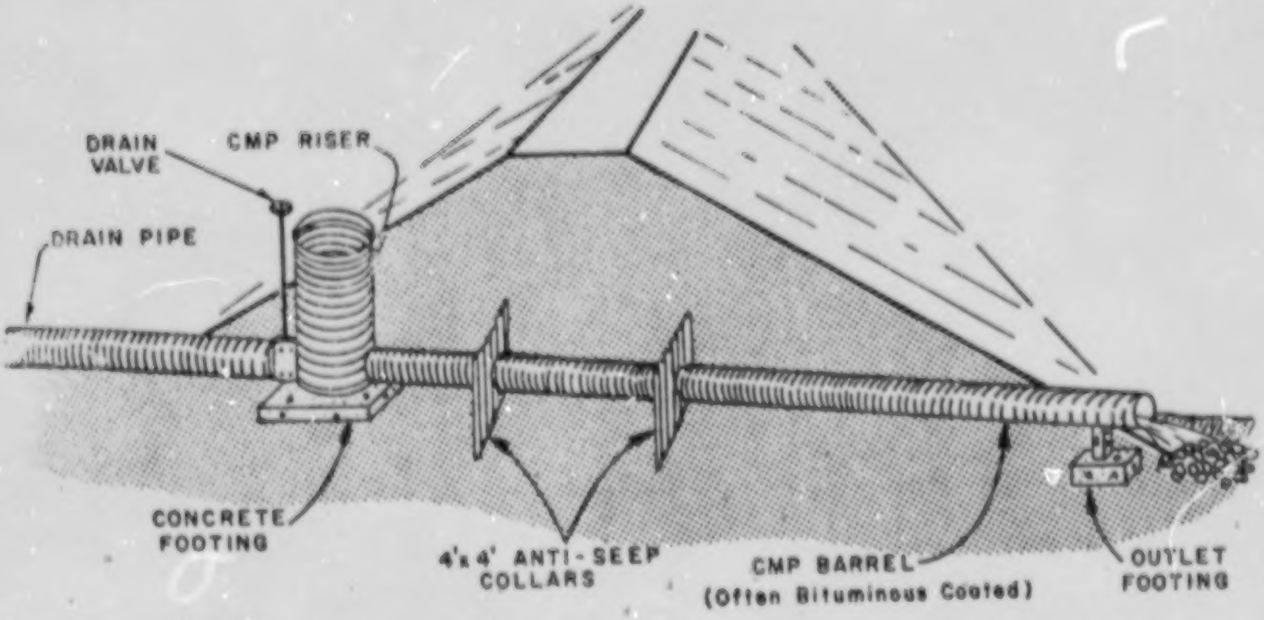

DRAIN VALVE
CMP RISER
DRAIN PIPE
CONCRETE FOOTING
4'x4' ANTI-SEEP COLLARS
CMP BARREL
(Often Bituminous Coated)
OUTLET FOOTING

Fig. 18. Corrugated Metal Pipe Outlet Works

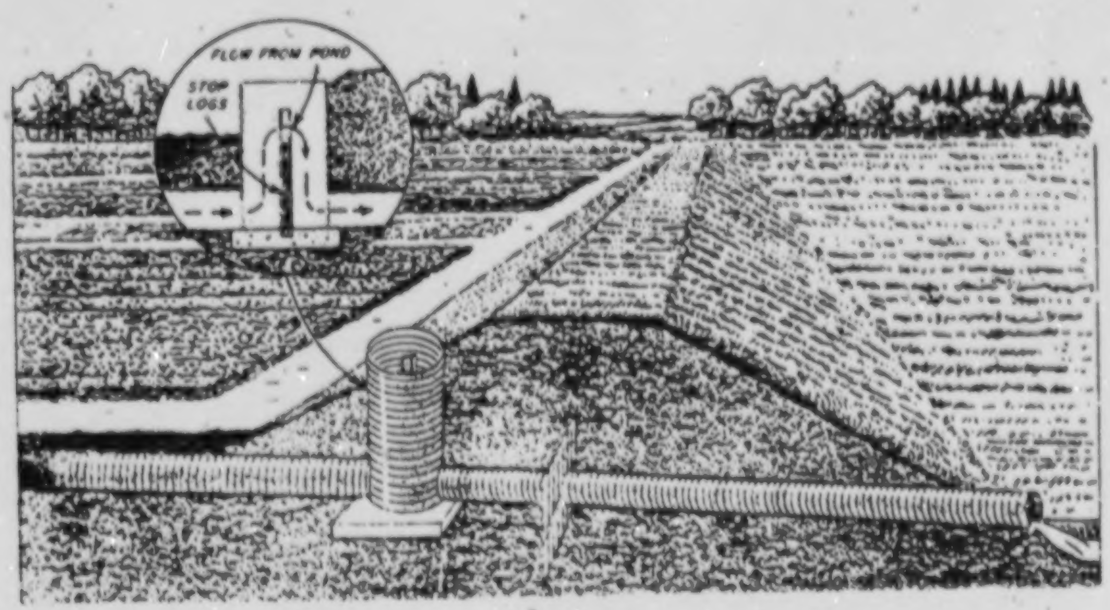

FLOW FROM POND
STOP LOGS

Fig. 19. CMP Outlet with Stop Logs (U.S. Soil Conservation Service, 1969)

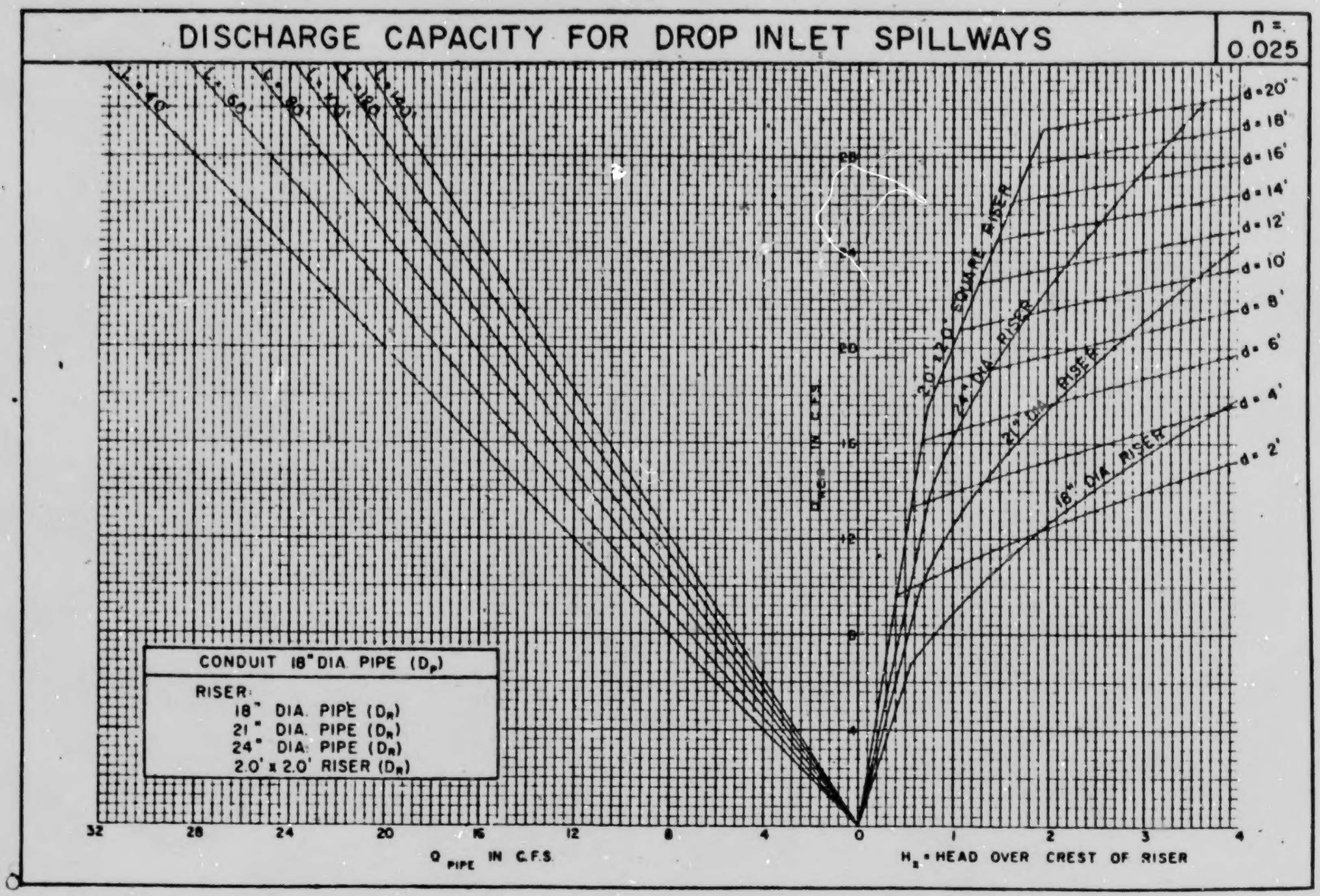


FIGURE 20 - TYPICAL PIPE SPILLWAY DESIGN CHART
(U.S. Soil Conservation Service, 1969)

CAPACITY OF CORRUGATED METAL PIPE CULVERTS
OUTLET CONTROL - FULL FLOW - WITHOUT HEADWALLS

CIRCULAR

DIAMETER	Length	CUBIC FEET PER SECOND																
		Head on Pipe - Feet																
INCHES		0.1	0.2	0.3	0.4	0.5	0.6	0.8	1.0	1.2	1.4	1.6	1.8	2.0	2.5	3.0	3.5	4.0
12	20 Feet	1.0	1.4	1.7	2.0	2.2	2.4	2.8	3.1	3.4	3.7	4.0	4.2	4.4	5.0	5.4	5.8	6.2
15		1.7	2.4	2.9	3.4	3.8	4.1	4.8	5.3	5.8	6.3	6.8	7.1	7.5	8.4	9.2	9.9	11
18		2.6	3.6	4.4	5.2	5.7	6.2	7.2	8.0	8.8	9.5	10	11	11	13	14	15	16
21		3.6	5.1	6.2	7.2	8.0	8.8	10	11	12	13	14	15	16	18	19	21	22
24		4.9	6.8	8.4	9.6	11	12	14	15	17	18	19	20	21	24	26	28	30
27		6.2	8.8	11	12	14	15	18	20	21	23	25	26	28	31	34	36	39
30		7.8	11	14	16	17	19	22	25	27	29	32	33	35	39	42	46	49
36		12	16	20	23	26	28	33	37	40	43	46	49	52	57	63	68	72
42		16	23	28	32	36	39	45	51	55	60	64	68	71	79	86	93	100
48		22	30	37	43	48	52	60	68	74	80	85	90	94	106	117	125	134
54		28	39	48	55	61	67	78	87	94	102	109	116	121	136	149	160	171
60		34	48	59	68	76	83	96	107	118	126	134	142	150	167	182	197	210
velocity							4		5	6			7		8	9	10	
12	40 Feet	0.8	1.1	1.4	1.6	1.8	2.0	2.3	2.5	2.8	3.0	3.2	3.4	3.6	4.0	4.4	4.8	5.1
15		1.4	1.9	2.4	2.7	3.1	3.4	3.9	4.3	4.8	5.2	5.5	5.9	6.2	6.9	7.6	8.2	8.8
18		2.1	3.0	3.7	4.3	4.8	5.2	6.0	6.8	7.4	8.0	8.6	9.0	9.6	11	12	13	14
21		3.0	4.3	5.3	6.1	6.8	7.4	8.6	9.6	11	12	12	13	14	15	17	18	19
24		4.2	5.9	7.2	8.4	9.4	10	12	13	15	16	17	18	19	21	23	25	27
27		5.5	7.8	9.6	11	12	14	16	17	19	21	22	23	25	28	30	33	35
30		7.0	9.8	12	14	16	17	20	22	24	26	28	30	31	35	38	42	44
36		10	15	18	21	24	26	30	33	36	39	42	45	47	53	58	62	66
42		15	21	26	30	33	36	42	47	51	55	59	62	66	74	80	88	93
48		20	28	35	40	45	49	56	63	69	74	80	84	89	99	109	118	127
54		26	36	45	51	57	63	72	81	89	96	103	109	115	128	140	152	163
60		32	45	55	64	72	78	90	100	110	120	128	136	143	160	175	190	202
velocity								4	5		6			7	8		9	10
12	60 Feet	0.7	1.0	1.2	1.4	1.6	1.7	2.0	2.2	2.4	2.6	2.8	2.9	3.1	3.5	3.8	4.1	4.4
15		1.2	1.7	2.1	2.4	2.7	3.0	3.4	3.8	4.2	4.5	4.8	5.1	5.4	6.0	6.6	7.1	7.6
18		1.9	2.7	3.3	3.8	4.2	4.6	5.3	5.9	6.5	7.0	7.5	8.0	8.4	9.3	10	11	12
21		2.7	3.9	4.8	5.5	6.1	6.6	7.7	8.7	9.3	10	11	12	12	14	15	16	17
24		3.8	5.4	6.6	7.6	8.4	9.2	11	12	13	14	15	16	17	19	21	22	24
27		5.0	7.1	8.7	10	11	12	14	16	17	19	20	21	22	25	27	29	31
30		6.4	9.0	11	13	14	16	18	20	22	24	25	27	28	32	35	37	40
36		9.7	14	17	19	22	24	27	31	33	36	38	41	43	48	52	56	60
42		14	19	24	28	31	34	39	44	48	51	55	58	61	68	74	80	86
48		19	27	32	38	42	46	53	59	64	69	74	78	82	92	100	108	116
54		24	34	42	48	54	59	68	77	83	90	96	102	108	120	131	142	152
60		31	43	53	61	68	74	86	97	105	113	120	128	135	150	166	178	190
								4		5		6			7	8	9	

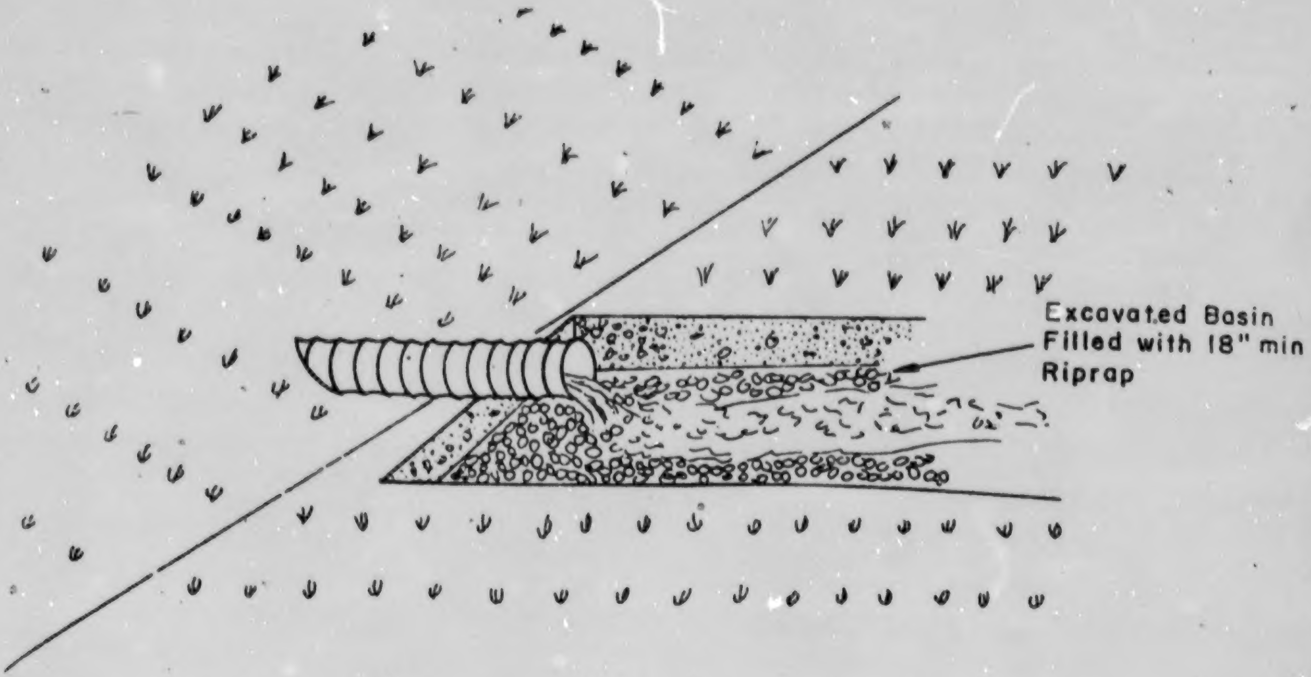
Fig. 21. Typical Pipe Design Table (U.S. Soil Conservation Service, 1969)

length along the conduit by 10 to 15 percent. These collars should be equally spaced along the middle two-fourths of the pipe.

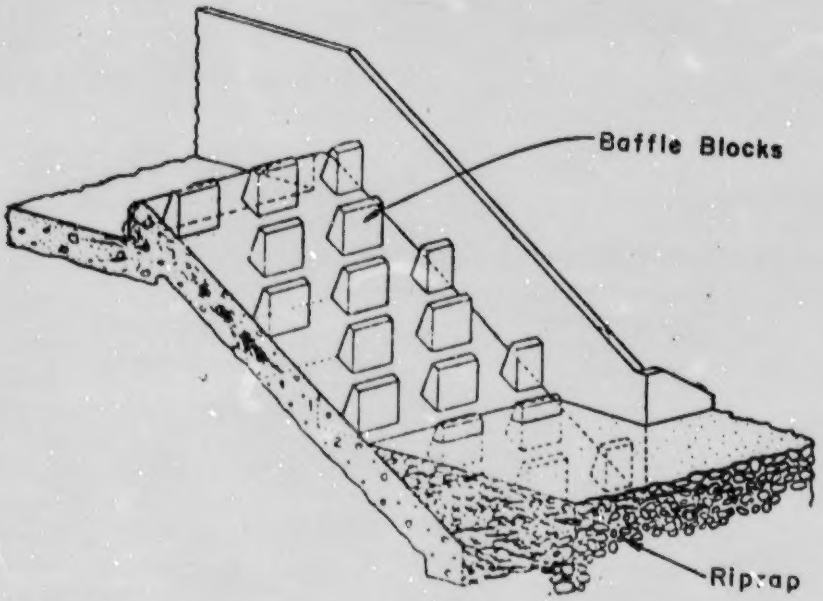
To prevent damage to the outlet works by settling, footings should be designed at inlet and outlet structures. A simple timber support (Figure 16), consisting of two posts with cross members is usually adequate for the outlet pipe. Placing conduits through the dam on a camber will also allow for settling. A camber at the centerline of the dam equal to about two percent of the fill height should be sufficient.

To prevent erosion of the downstream toe, a stilling basin of some form is needed at the barrel outlet. For a chute or monolithic structure, a diverging channel with baffle blocks, such as Figure 22b, is a well-suited energy dissipator. For simple pipe outlets, a basin of riprap (Figure 22a) is usually sufficient. The minimum size for such a basin should be 15' X 5' with a thickness of 18". If high velocities are expected through the outlet, the riprap basin can be combined with a manifold basin to effectively reduce velocity head (Figure 23). This type outlet, developed at Colorado State University by Fiala and Albertson (1960), is easily constructed by laying the last section of outlet pipe on an adverse slope and partially obstructing the orifice with a slatted cover. This is a good method to dissipate energy, but adequate support of the outlet works should be insured in the design to prevent movement due to dynamic forces. Any type stilling basin used should be designed well downstream of the dam toe to prevent scouring.

Several design considerations should also be made to prevent the conduit from becoming clogged. Six inches should be the minimum diameter for outlet works. Some type of debris trap should be affixed to any inlet structure. For a metal pipe riser, this can simply be a rack of several reinforcing bars welded over the inlet, as in Figure 24. For concrete inlets (Figure 14), bars can be laid across the orifice. Such a trap should allow passage of small objects to avoid clogging the trap itself and, thus, increasing the riser crest elevation. For vertical pipe risers, an anti-vortex baffle should be included in the debris trap (Figure 24a) to prevent harmful vortex turbulence. The outlet opening at the toe should be covered with a hinged door or bars to prevent animals from entering and clogging the conduit with debris.


Excavated Basin
Filled with 18" min
Riprap

(a) Riprap Basin


Baffle Blocks
Riprap

(b) Reinforced Concrete Basin

Fig. 22. Stilling Basins

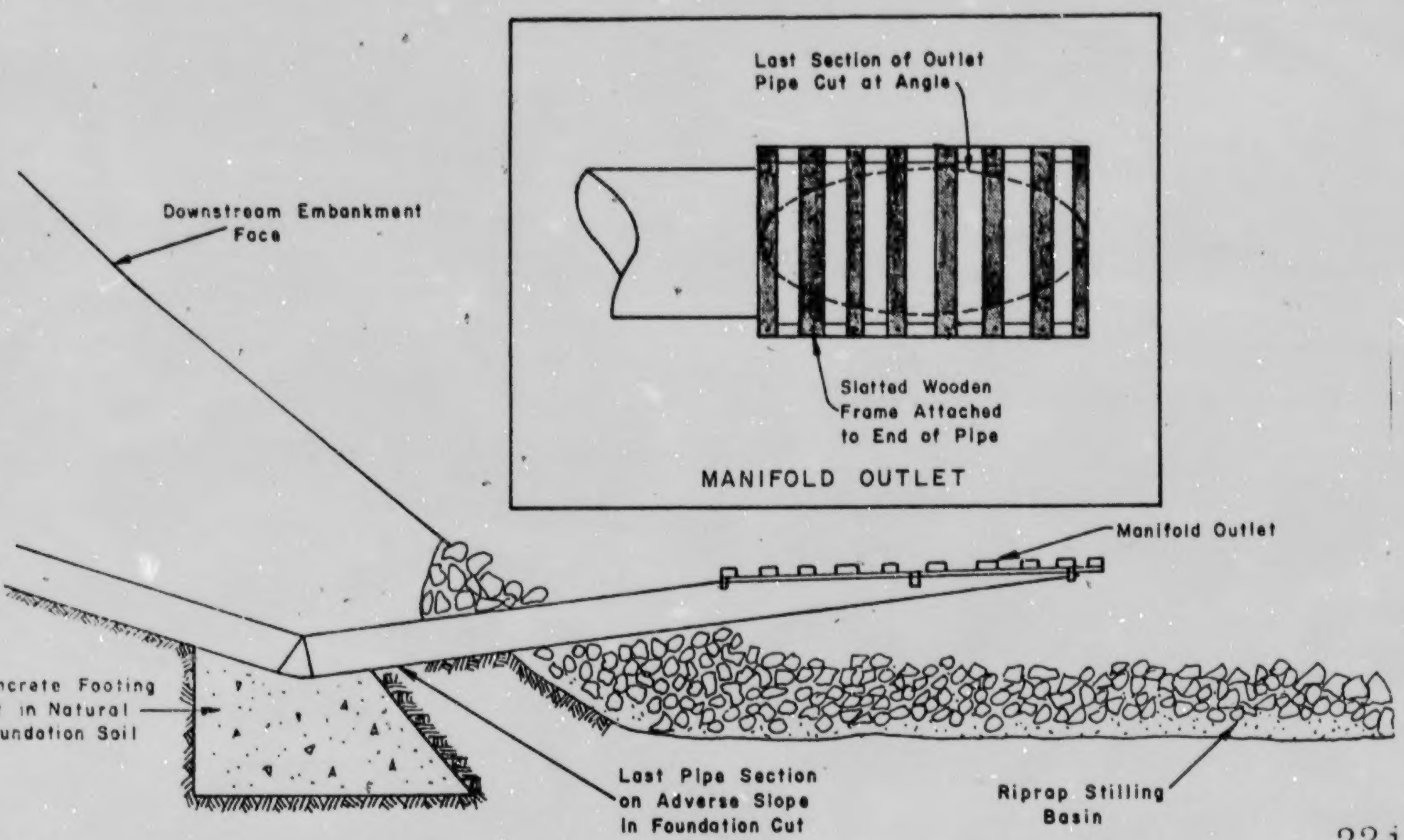
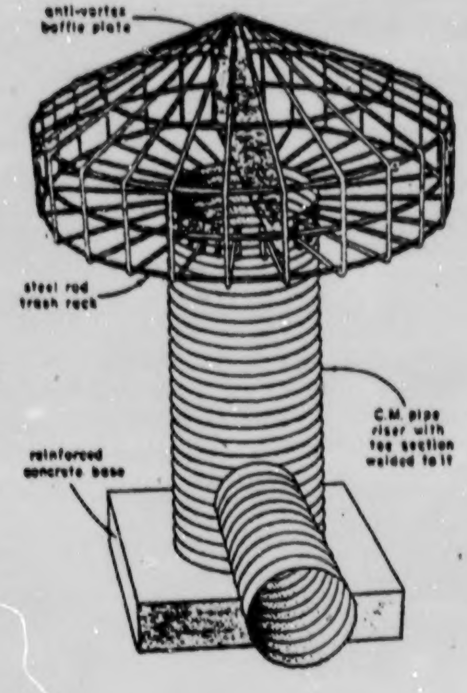
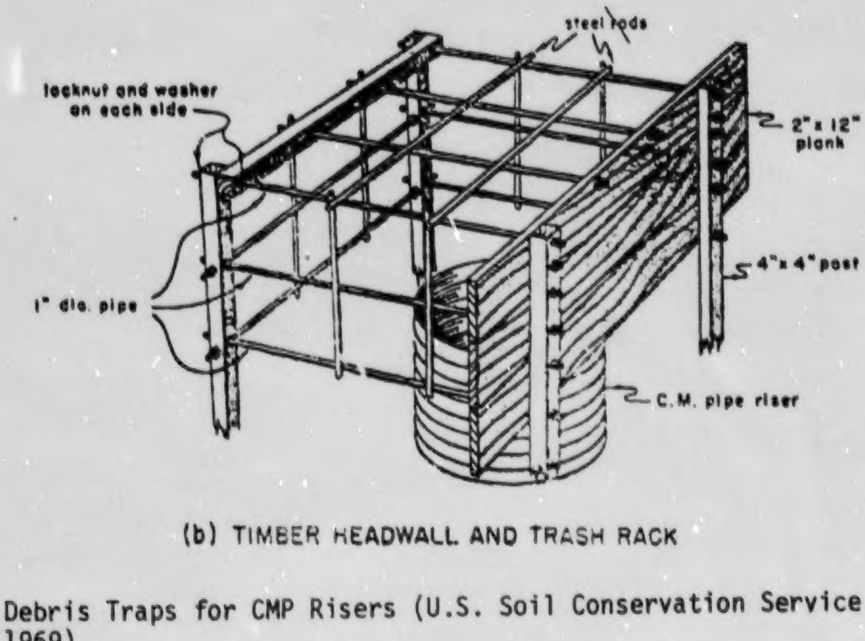

Last Section of Outlet Pipe Cut at Angle
Slatted Wooden Frame Attached to End of Pipe
MANIFOLD OUTLET
Downstream Embankment Face
Manifold Outlet
Concrete Footing Set in Natural Foundation Soil
Last Pipe Section on Adverse Slope in Foundation Cut
Riprap Stilling Basin

FIGURE 23 – MANIFOLD BASIN


anti-vortex baffle plate
steel rod trash rack
C.M. pipe riser with tee section welded to it
reinforced concrete base

(a) CORRUGATED METAL PIPE RISER WITH CONICAL TRASH RACK AND BAFFLE


steel rods
locknut and washer on each side
2" x 12" plank
4" x 4" post
1" dia. pipe
C.M. pipe riser

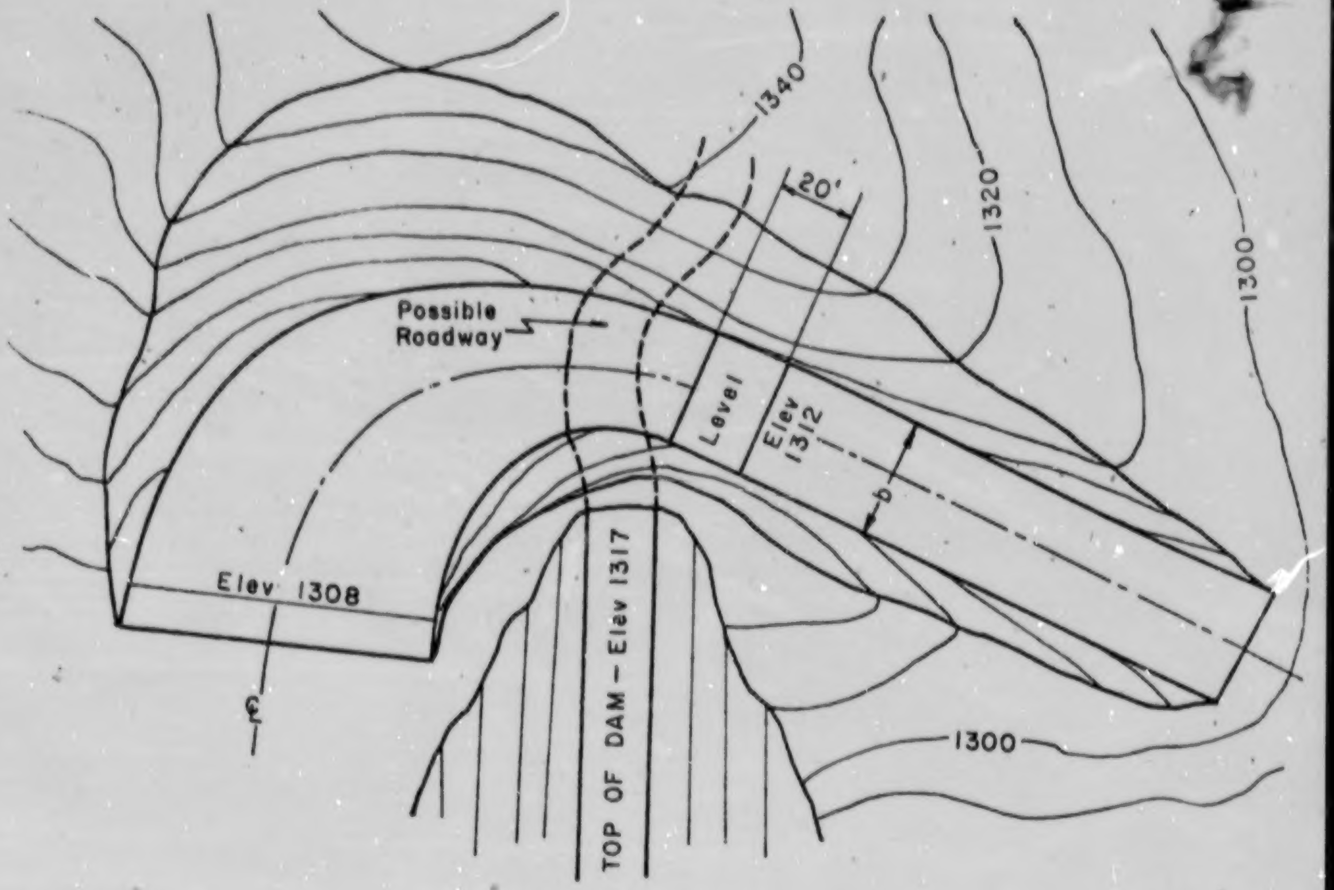
(b) TIMBER HEADWALL AND TRASH RACK

Fig. 24. Debris Traps for CMP Risers (U.S. Soil Conservation Service, 1969)

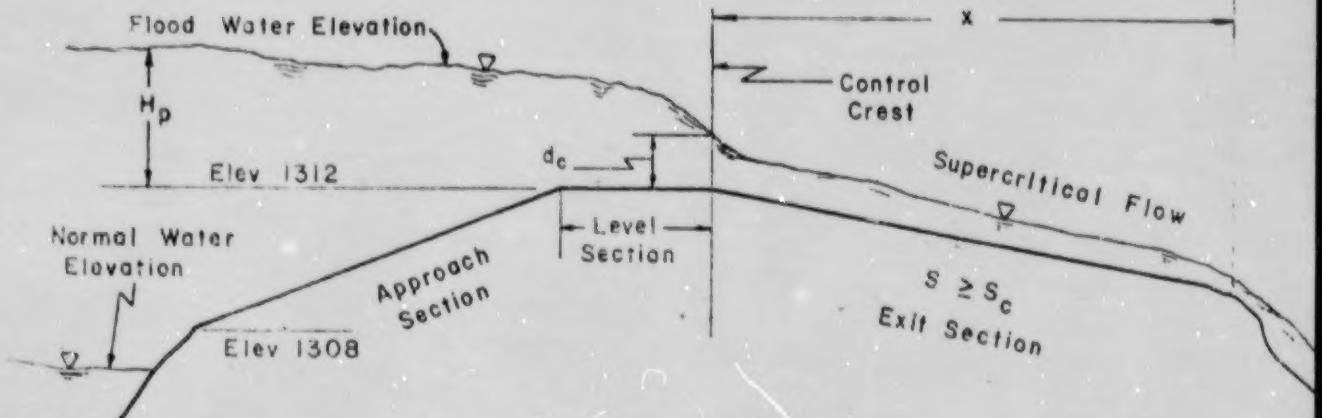
Spillways. To safely by-pass flood runoffs that exceed the storage capacity of the pond, an emergency or flood spillway must be provided. If a natural saddle in the topography exists at some point on the pond's edge, this could prove adequate if large enough. If no such depression exists, a channel must be designed through at least one of the dam's abutments. Such an earth spillway should never be constructed on or near fill material.

An emergency spillway consists of three sections, as shown in Figure 25: an approach section, a control level, and an exit channel. Flow enters through the approach section and becomes critical flow at the control crest of the level section (Figure 25b). The flow is then discharged at the designed conditions, through the exit section if the exit slope is equal to or greater than cirtical slope. The approach channel should have a slope of not less than three percent to insure drainage, and an entrance width at least 50 percent greater than the control section. The control crest should be located near the extended centerline of the dam, with the level section upstream of the control crest. The level section should be at least 20 feet long to be stable. The exit section should be as straight as possible and confine the outflow until it is a safe distance from the embankment fill. There the water can be released into ditches for spreading or returned to the natural waterway. Although the exit slope must be critical or greater, it should not produce velocities which will cause erosion of the spillway cover. Thus, maximum velocities usually should not exceed 6 fps. If higher velocities would occur because of an inability to construct a flatter slope, riprap or a drop structure should be considered.

As with the outlet works, the design specifications for earth spillways are most easily obtained from design tables such as Figure 26. Such tables will suggest several combinations of spillway widths, lengths, and slopes which will accommodate the design peak flow. Any combination chosen should produce a velocity in the exit section below the maximum permissible. If such tables are not available, application of the broad-crested weir formula and waterway design procedures can be utilized to determine the cross-section area of the control section and the exit slope required. The side slopes of the spillway channel should not exceed 2:1 and the bottom width should not exceed 35 times the design depth of flow in the control


1340
1320
1300
20'
Possible Roadway
Level
Elev 1312
b
Elev 1308
℄
TOP OF DAM – Elev 1317
1300

(a) Layout and Grading


Flood Water Elevation
x
Control Crest
H_p
d_c
Elev 1312
Supercritical Flow
Normal Water Elevation
Level Section
Approach Section
S ≥ S_c
Exit Section
Elev 1308

(b) Profile Along ℄ of Spillway

Fig. 25. Typical Earth Spillway

DESIGN DATA FOR EARTH SPILLWAYS

SIDE SLOPE 3:1

SOD OR GRASS COVER
n = 0.040

STAGE (Hp) IN FEET	SPILLWAY VARIABLES	BOTTOM WIDTH (b) IN FEET																
		8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	38	40
0.5	Q	7	8	9	10	12	14	14	16	17	18	20	21	22	24	25	27	28
	V	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7
	S	3.9	3.9	3.9	3.9	3.9	3.9	3.9	3.8	3.8	3.8	3.8	3.8	3.8	3.8	3.8	3.8	3.8
	X	33	33	33	33	33	33	33	33	33	33	33	33	33	33	33	33	33
0.6	Q	9	11	12	14	16	18	20	22	24	26	27	29	30	31	32	34	35
	V	2.9	2.9	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0
	S	3.7	3.7	3.7	3.7	3.7	3.7	3.7	3.7	3.6	3.6	3.6	3.6	3.6	3.6	3.6	3.6	3.6
	X	36	36	36	36	36	37	37	37	37	37	37	37	37	37	37	37	37
0.7	Q	11	14	16	19	21	24	26	29	31	33	36	38	41	43	45	48	[illegible]
	V	3.2	3.2	3.2	3.2	3.2	3.2	3.2	3.2	3.3	3.3	3.3	3.3	3.3	3.3	3.3	3.3	3.3
	S	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.4	3.4	3.4	3.4	3.4	3.4	3.4	3.4	3.4	3.4
	X	40	40	40	40	41	41	41	41	41	41	41	41	41	41	41	41	41
0.8	Q	14	17	20	23	26	30	32	35	38	42	45	47	50	52	55	58	60
	V	3.5	3.5	3.5	3.6	3.5	3.6	3.6	3.6	3.6	3.6	3.6	3.6	3.6	3.6	3.6	3.6	3.6
	S	3.3	3.3	3.3	3.2	3.2	3.2	3.2	3.2	3.2	3.2	3.2	3.2	3.2	3.2	3.2	3.2	3.2
	X	44	44	44	44	45	45	45	45	45	45	45	45	45	45	45	45	45
0.9	Q	19	22	25	29	32	36	40	43	47	51	55	59	63	66	68	73	76
	V	3.7	3.7	3.8	3.8	3.8	3.8	3.8	3.8	3.8	3.8	3.8	3.8	3.8	3.8	3.8	3.8	3.8
	S	3.1	3.1	3.1	3.1	3.1	3.1	3.1	3.1	3.1	3.1	3.1	3.1	3.1	3.1	3.1	3.1	3.1
	X	48	48	48	48	48	48	48	48	48	48	49	49	49	49	49	49	49
1.0	Q	20	27	30	35	38	43	48	52	56	61	64	69	74	79	82	85	92
	V	3.9	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0
	S	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0
	X	52	52	52	52	52	52	52	52	52	52	52	52	52	52	52	52	52
1.1	Q	25	31	34	40	45	48	54	60	65	70	74	79	84	90	95	100	105
	V	4.1	4.1	4.2	4.2	4.2	4.2	4.2	4.2	4.2	4.2	4.2	4.3	4.3	4.3	4.3	4.3	4.3
	S	2.9	2.9	2.9	2.9	2.9	2.9	2.9	2.9	2.9	2.8	2.8	2.8	2.8	2.8	2.8	2.8	2.8
	X	55	55	56	56	56	56	56	56	56	56	56	56	56	56	56	56	56
1.2	Q	33	37	42	47	52	59	65	71	76	82	88	92	99	105	110	116	122
	V	4.3	4.3	4.4	4.4	4.4	4.4	4.4	4.4	4.4	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5
	S	2.9	2.9	2.8	2.8	2.8	2.8	2.8	2.8	2.8	2.8	2.8	2.8	2.8	2.8	2.8	2.8	2.9
	X	59	59	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60
1.3	Q	35	42	48	55	62	68	75	82	89	95	101	109	116	122	127	134	140
	V	4.5	4.5	4.6	4.6	4.6	4.6	4.6	4.6	4.6	4.6	4.6	4.6	4.7	4.7	4.7	4.7	4.7
	S	2.8	2.8	2.8	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7
	X	63	63	64	64	64	64	64	64	64	64	64	64	64	64	64	64	64
1.4	Q	40	48	56	64	70	78	86	93	100	104	114	121	130	138	146	152	159
	V	4.7	4.7	4.7	4.8	4.8	4.8	4.8	4.8	4.8	4.8	4.8	4.8	4.8	4.9	4.9	4.9	4.9
	S	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6
	X	67	67	67	68	68	68	68	68	68	68	68	68	68	68	68	68	68
1.5	Q	49	54	63	71	82	88	96	106	113	121	128	136	144	154	164	173	182
	V	4.8	4.9	4.9	4.9	4.9	4.9	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.1
	S	2.7	2.7	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.5	2.5	2.5
	X	72	72	72	72	72	72	72	72	72	72	72	72	72	72	72	72	72
1.6	Q	52	60	70	81	90	100	110	118	129	137	145	155	162	172	182	192	201
	V	4.9	5.0	5.1	5.1	5.1	5.1	5.1	5.1	5.1	5.2	5.2	5.2	5.2	5.2	5.2	5.2	5.2
	S	2.6	2.6	2.6	2.6	2.6	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5
	X	76	76	76	76	76	76	76	76	76	76	76	76	76	76	76	76	76
1.7	Q	58	69	78	90	100	110	121	132	141	149	160	168	179	190	201	212	222
	V	5.0	5.2	5.2	5.3	5.3	5.3	5.3	5.3	5.3	5.3	5.3	5.3	5.3	5.4	5.4	5.4	5.4
	S	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5
	X	80	80	80	80	80	80	80	80	80	80	80	80	80	80	81	81	81
1.8	Q	65	75	89	100	110	122	133	145	155	166	175	188	196	208	220	232	243
	V	5.3	5.3	5.4	5.4	5.4	5.4	5.4	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5
	S	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4
	X	83	84	84	84	84	84	84	84	84	84	84	84	84	84	84	84	85
1.9	Q	72	84	98	110	124	134	148	160	172	182	192	204	218	232	240	253	266
	V	5.4	5.4	5.5	5.6	5.6	5.6	5.6	5.6	5.6	5.6	5.6	5.6	5.7	5.7	5.7	5.7	5.7
	S	2.5	2.5	2.5	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4
	X	88	87	88	88	88	89	88	88	88	88	89	88	89	89	89	89	89
2.0	Q	79	94	107	120	133	148	160	172	186	197	212	223	236	252	265	[illegible]	291
	V	5.5	5.6	5.6	5.7	5.7	5.7	5.7	5.8	5.8	5.8	5.8	5.8	5.8	5.8	5.9	5.9	5.9
	S	2.5	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.3	2.3	2.3	2.3	2.3	2.3	2.3	2.3	2.3
	X	90	92	92	92	92	92	92	92	92	92	92	92	92	93	93	93	93
2.1	Q	89	103	118	132	146	160	176	190	202	217	229	241	255	271	286	[illegible]	[illegible]
	V	5.6	5.7	5.8	5.8	5.8	5.9	5.9	5.9	5.9	5.9	5.9	5.9	6.0	6.0	6.0	6.0	6.0
	S	2.4	2.4	2.4	2.4	2.4	2.3	2.3	2.3	2.3	2.3	2.3	2.3	2.3	2.3	2.3	2.3	2.3
	X	94	95	95	95	95	95	95	96	96	96	96	96	97	97	97	97	97
2.2	Q	95	112	126	143	158	176	192	204	[illegible]	234	246	263	280	297	313	331	349
	V	5.7	5.8	5.9	5.9	6.0	6.0	6.0	6.0	6.1	6.1	6.1	6.1	6.1	6.1	6.1	6.1	6.1
	S	2.4	2.4	2.4	2.3	2.3	2.3	2.3	2.3	2.3	2.3	2.3	2.3	2.3	2.3	2.3	2.3	2.3
	X	99	99	99	100	100	101	101	101	101	101	101	101	102	102	102	102	102
2.3	Q	104	120	138	155	172	190	205	222	236	251	266	283	299	319	336	354	367
	V	5.8	5.9	6.0	6.1	6.1	6.1	6.1	6.2	6.2	6.2	6.2	6.2	6.2	6.2	6.3	6.3	6.3
	S	2.4	2.4	2.3	2.3	2.3	2.3	2.3	2.3	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2
	X	103	104	104	105	105	105	106	106	106	106	106	106	106	106	106	106	106
2.4	Q	114	132	150	168	185	205	222	237	252	269	288	303	321	340	359	[illegible]	392
	V	6.0	6.0	6.1	6.2	6.2	6.3	6.3	6.3	6.3	6.3	6.3	6.3	6.3	6.4	6.4	6.4	6.4
	S	2.3	2.3	2.3	2.3	2.3	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2
	X	109	109	109	109	109	109	109	110	110	110	110	110	110	110	[illegible]	[illegible]	[illegible]

Fig. 26. Typical Emergency Spillway Design Table (Prepared by U.S. Soil Conservation Service)

section. If this width would be exceeded, consideration must be given to the use of a spillway at each abutment.

The spillway bottom must be level and should be protected with a good sod growth. If climate or soil prohibit such growth, bare original earth will suffice, but the permissible velocity must be decreased. Riprap should be placed wherever outflow may damage fill material. If the dam crest is to serve as a roadway, the road should cross the spillway upstream of the level section (Figure 25a). This will maintain good cover and dimensions in the control and exit sections.

Construction

Site preparation. After an appropriate design has been developed, all cuts, fills, and structures should be located at the site by staking, as shown in Figure 27.

Stakes, offset one foot, should be placed along the top width of the cutoff or key trench, and the desired cut noted. The embankment is best located by stakes at 50 feet or less intervals along the upstream and downstream toes. The proper slope and top width will be denoted by these stakes on the abutments. The earth spillway is located by cut stakes along the lines of intersection of the side slopes and the original surface. Similar cut stakes should also mark the normal water elevation along the natural contour. After the proper level of fill has been reached, stakes indicating the position of inlets, seepage collars, conduits, and outlet works should be set in place.

Once the limits of the pond have been staked out, the site can be cleared and the embankment foundation prepared. All growth within the pond, spillway, and dam areas should be removed. Any large growth, which might later cause bank erosion, should also be removed from the pond's perimeter. Stripping of any unsuitable soil from the dam foundation is also necessary. Scarifying to a depth of six inches should be done to improve the bond between embankment and foundation materials.

If the outlet works are to be placed along the natural waterway, a diversion channel will be necessary to carry runoff around the embankment until the outlet has been constructed. If high flows are not expected

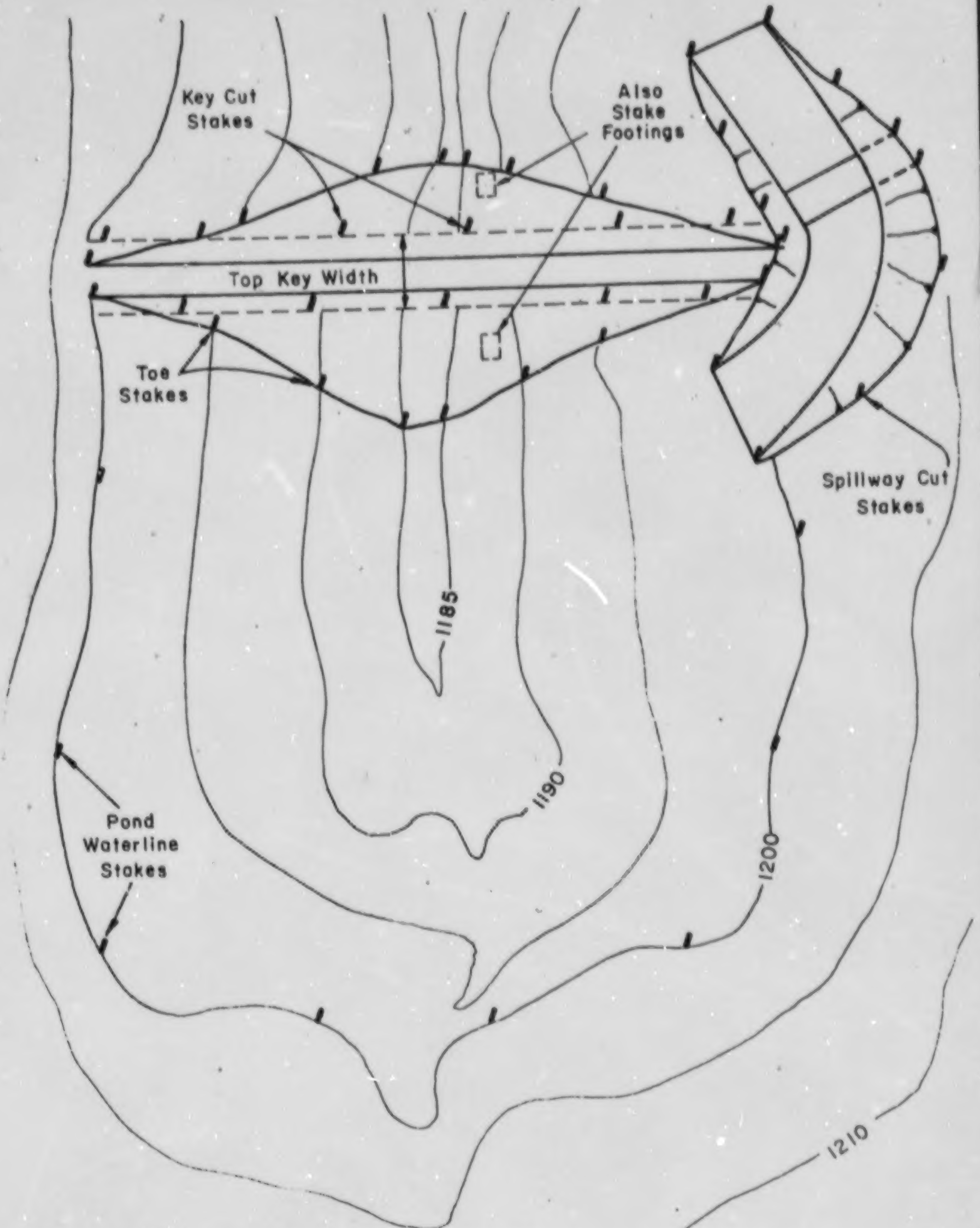

Key Cut
Stakes
Also
Stake
Footings
Top Key Width
Toe
Stakes
Spillway Cut
Stakes
1185
1190
Pond
Waterline
Stakes
1200
1210

Fig. 27. Staking Layout

during this time, the channel can be excavated through one side of the foundation. Should high flows be probable, a timber flume, such as Figure 28, would be better suited to contain flow.

Excavation. As a continuation of the foundation preparation, the key or cutoff trench should be the first major excavation. The excavated material can be stockpiled to later be used in a pervious zone of the dam, to be spread on the pond bottom or removed altogether. Dewatering of any seepage into the trench should be done until impervious backfill can be compacted into the trench.

In steep valley sites, abutments should be excavated a few feet to improve slipping resistance with the embankment. Excavation of the pond area material to be used in the embankment is usually done simultaneously during embankment filling. However, any topsoil should be stockpiled for later use on seeded areas. Likewise, the cut material from the earth spillway can be used on the embankment. If it will not be disturbed during embankment fill operations, the earth spillway can be fertilized and seeded before dam completion to give the sod an early start.

Excavation of borrow material to be used as an impervious zone should be checked and screened, if necessary, to remove large rocks and organic material.

Embankment. The proper placement and compaction of fill material should be the major concerns of earth dam construction. The fill material should be spread in thin layers along the entire length of the dam. For machinery compaction, these layers should be eight to ten inches thick for pervious soils and four to six inches for cohesive soils. Wherever hand tamping is done, these layers should not exceed four inches. The height of fill should progress evenly across the entire dam length except where diversion is necessary. Continuous checks should be made during compaction to see that optimum moisture and a good density are maintained. For earth dams, compaction should be 85 to 100 percent of the maximum Proctor density. If soil is too dry, sprinkling after placement or irrigation of the borrow area should be taken not to intermix pervious materials. However, all zones

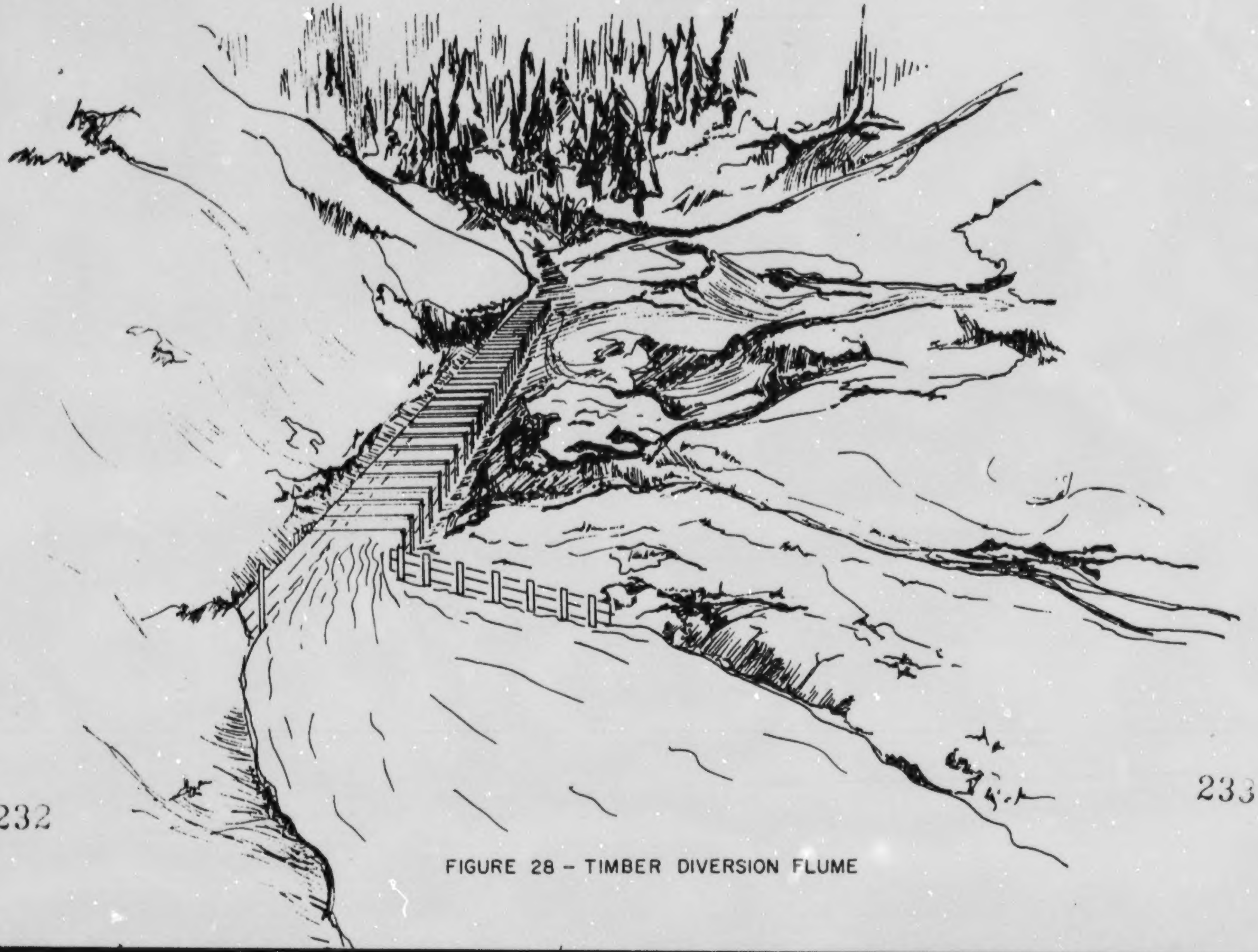


FIGURE 28 – TIMBER DIVERSION FLUME

should fill evenly to insure compaction. As the proper elevations are reached, any structures should be placed, and special care taken to insure compaction of fill around them. This is best accomplished with hand or pneumatic tampers. Four feet of hand tamped fill should be put over conduits before allowing heavy machinery to move over it. Fill and compaction operations should cease during rain or freezing weather which would hamper compaction. As previously mentioned, vibrating, sheep's foot rollers provide good compaction, but for small dams, routing available equipment across the embankment should suffice.

Forms used to build concrete outlet works should be removed before backfilling and all pipe and collar connections should be checked for water tightness.

Upon completion of fill operations, all slopes should be trimmed to remove excess soil which may cause small slides and erosion. Wherever vegetation is to protect the slopes, a good layer of top soil should be provided. Riprap should be carefully placed to prevent segregation of sizes.

Inspection, maintenance, and operation

Inspection of the pond during construction is important to insure conformity with design. This basically involves checking elevations, testing moisture and compaction, and inspecting placement of outlet works. Once completed and a good sod cover has developed, a farm pond requires a minimum of maintenance. Fencing should be placed where necessary to prevent livestock from destroying banks, especially on spillways and the dam.

Regular inspections of the pond should be made to spot needed repairs. Rills or washes on the dam and spillway should be filled, compacted, and resodded. Vegetation on the dam should be mowed and fertilized to promote good root growth. Under no conditions should woody growth be permitted on or near the embankment. Disturbance of riprap by wave action should be corrected.

Inspections during rapid changes in the water level due to flooding or drawdown should be made to check for sloughing or cracking.

Phreotophyte and algae growth in the pond should be prevented. However, some small dense vegetation on the bank may be useful to catch sediment runoff.

To prevent health hazards around the pond, water containing waste materials should be diverted from ponds, and rodents and insects should be controlled.

With careful planning and construction, a pond can effectively conserve soil and water resources with a minimal amount of maintenance.

APPENDIX

Since the cross section design of earth embankments should be a function of the available construction materials, a guide to soil permeability and location of seepage is needed to properly position water barriers and drains.

Figure A1 suggests a classification by particle size distribution to better recognize the permeability of soils. With this guide, the subsurface investigations of dam sites can be analyzed to determine if borrow material must be located for an impervious core or blanket. Furthermore, the embankment foundation can be evaluated for its ability to retard water seepage under the dam. Of course, seepage takes place through any dam material, even concrete. However, by locating this seepage and designing for it, damage by piping can be avoided.

Figure A2 illustrates positions of the seepage line through embankments of homogeneous material. This seepage or saturation line is the gradient above which there is no hydrostatic pressure. As seen in Figure A2a and A2b, seepage will occur on the downstream face of an embankment of impervious material without drainage whether the foundation is pervious or not. For an impervious foundation, the seepage can egress through a filter blanket (Figure A2c). If a shallow pervious foundation is present, a cutoff and/or rock toe drain should safely drawdown the saturation line (Figure A2d). The cutoff allows the downstream pervious foundation to act as a drainage blanket. If available materials warrant the use of an impervious core, the seepage line should be drawn as in Figure A3a for an impervious foundation. In this case, the downstream pervious embankment material serves as a drain. Where the foundation is about as permeable as the core, the seepage through it will appear as Figure A3b. If the foundation is any more permeable, a cutoff trench should again be utilized. However, in any zoned embankment, some protection should be provided at the downstream toe to insure against piping; either a drain or riprap cover with a gravel filter.

As demonstrated in Figures A2c and A3b, the seepage line is actually a boundary for drawing the entire flow net through a dam. This flow net consists of two sets of lines; flow lines, which approximate the actual path

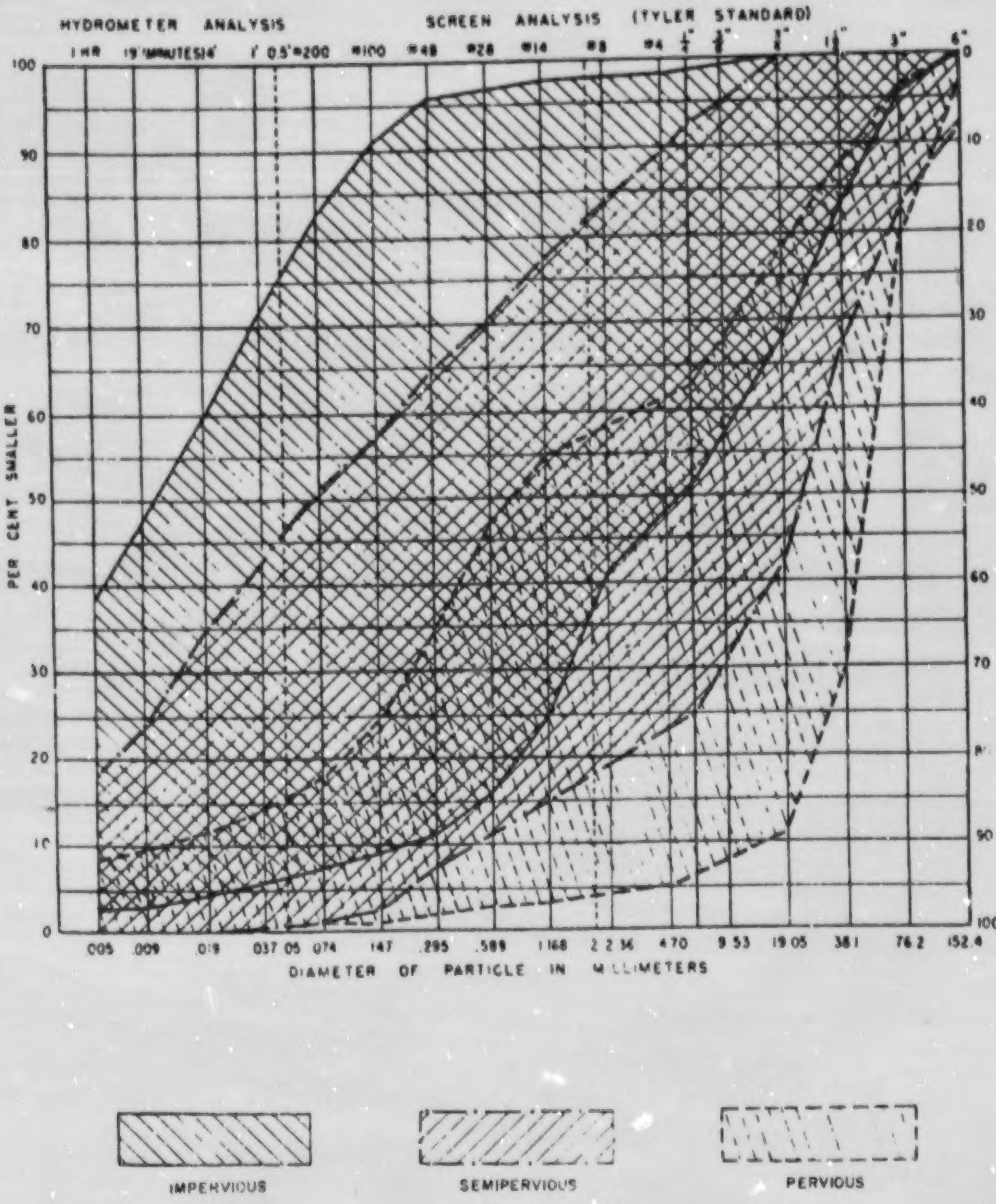
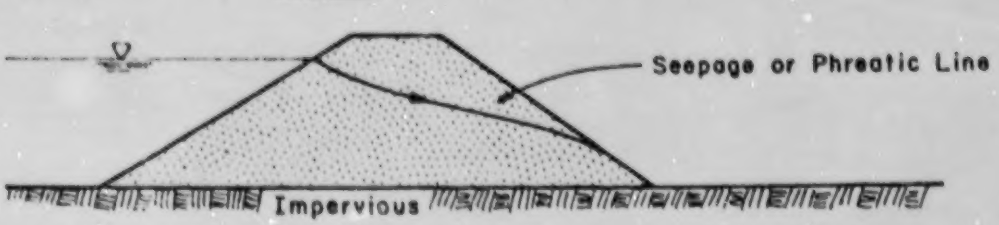
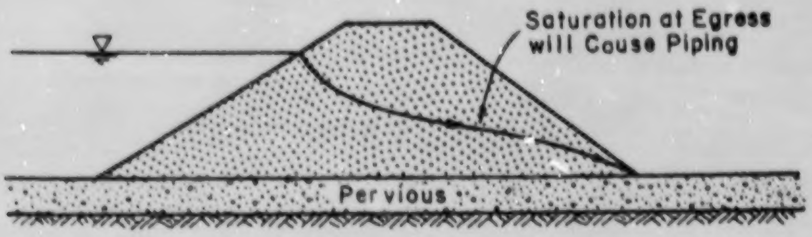


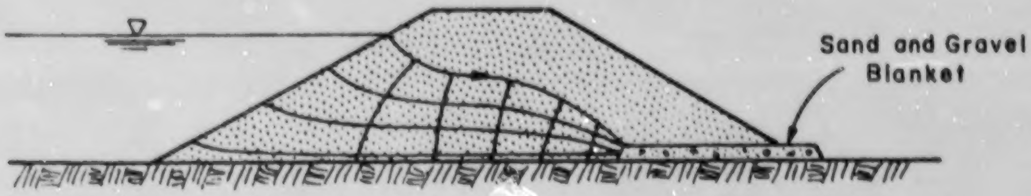
Fig. A1. Particle Size Distribution for Typical Soil Types (Bureau of Reclamation, 1948)


Seepage or Phreatic Line
Impervious

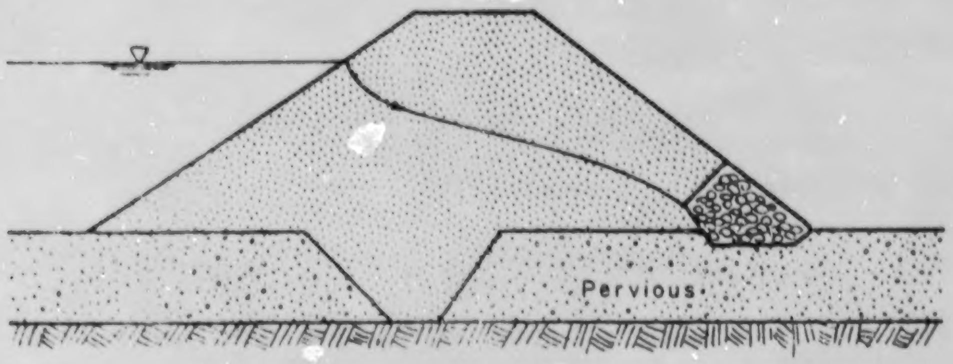
(a) Impervious Foundation without Drainage


Saturation at Egress will Cause Piping
Pervious

(b) Pervious Foundation without Drainage

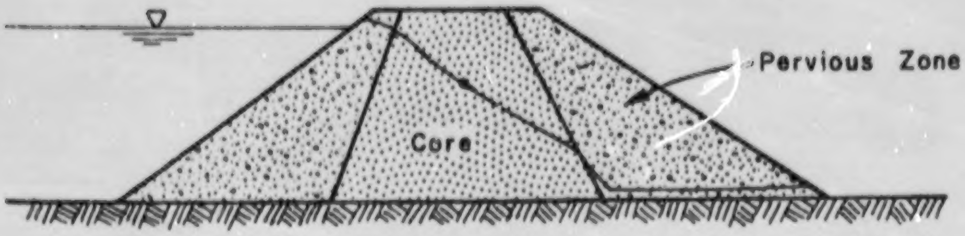

Sand and Gravel Blanket

(c) Impervious with Filter

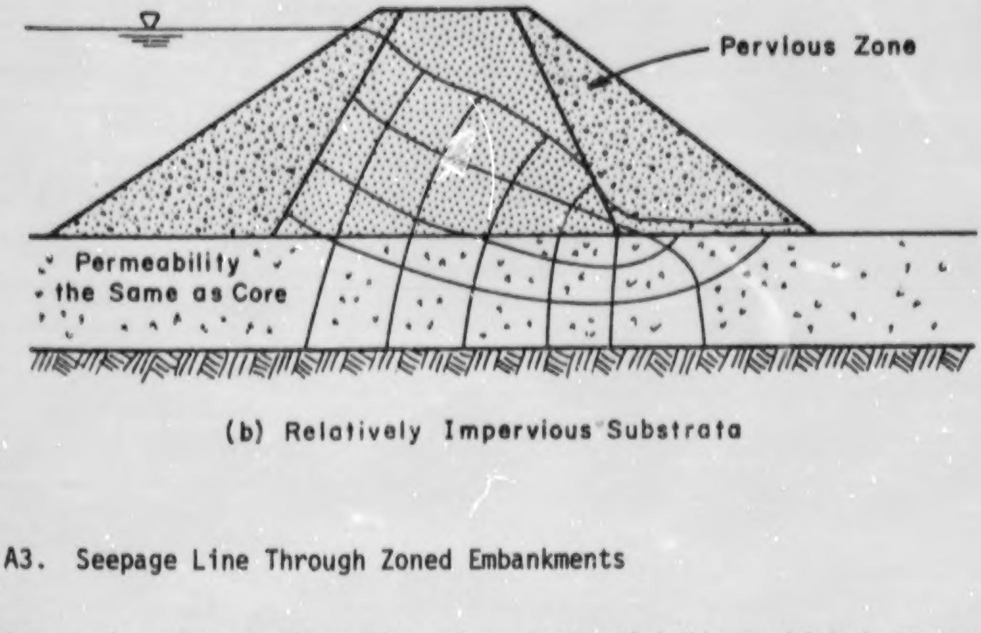


(d) Pervious with Cutoff and Drain

Fig. A2. Seepage Lines Through Homogeneous Embankments


Pervious Zone
Core

(a) Impervious Foundation


Pervious Zone
Permeability the Same as Core

(b) Relatively Impervious Substrata

Fig. A3. Seepage Line Through Zoned Embankments

of water moving through the soil, and equipotential lines which indicate gradients of equal hydrostatic pressure. The intersections of these lines occur at right angles, which aids in the drawing of the flow net. As in Figure A3b, the lower boundary of the flow net is any impervious layer, and the resulting diagram should appear as a series of homologous rectangles.

Some excellent guides to constructing flow nets are given by Arthur Casagrande, "Seepage Through Dams" (1937).

While construction of flow nets gives a good picture of the entire seepage pattern, the main concern is knowing where the saturation line will egress on the downstream slope and what quantity of seepage can be expected. Although complex approaches to these problems can quite accurately predict results, an approximate method has been developed by Creager, et al. (1945), which yields adequate results for small earth dams. This method can be used for homogeneous or zoned cross sections. In a zoned embankment, the pervious zones are considered to be much more permeable than any impervious core and, thus, have practically no influence on the position of the seepage line. As seen in Figure A3b, the seepage line through a pervious zone can be drawn almost horizontal, and then the impervious core is handled the same as a homogeneous cross section. Referring to Figure A4, this method begins with the assumption that:

$$e = \frac{h}{3} \qquad (1)$$

where

e = the vertical distance from the impervious foundation to the egress of the seepage line, and

h = the vertical distance from the impervious foundation to the water level in the pond.

By applying Darcy's law for moisture movement through soil, the seepage discharge through the dam is:

$$q = \frac{k(h-e)}{L}\,\frac{(h+e)}{2} = \frac{k}{2}\,\frac{(h^2-e^2)}{L} \qquad (2)$$

where

q = discharge in any units of volume per time,

k = hydraulic conductivity of the soil (a sample of k values is given in Figure A5), and

L = mean length of seepage path.

As shown in Figure A4, this length L is found by the expression

$$L = (1.3\ h + 2\ z - \frac{e}{2})\cot\alpha + W \qquad (3)$$

where

z = vertical distance from headwater to top of dam,

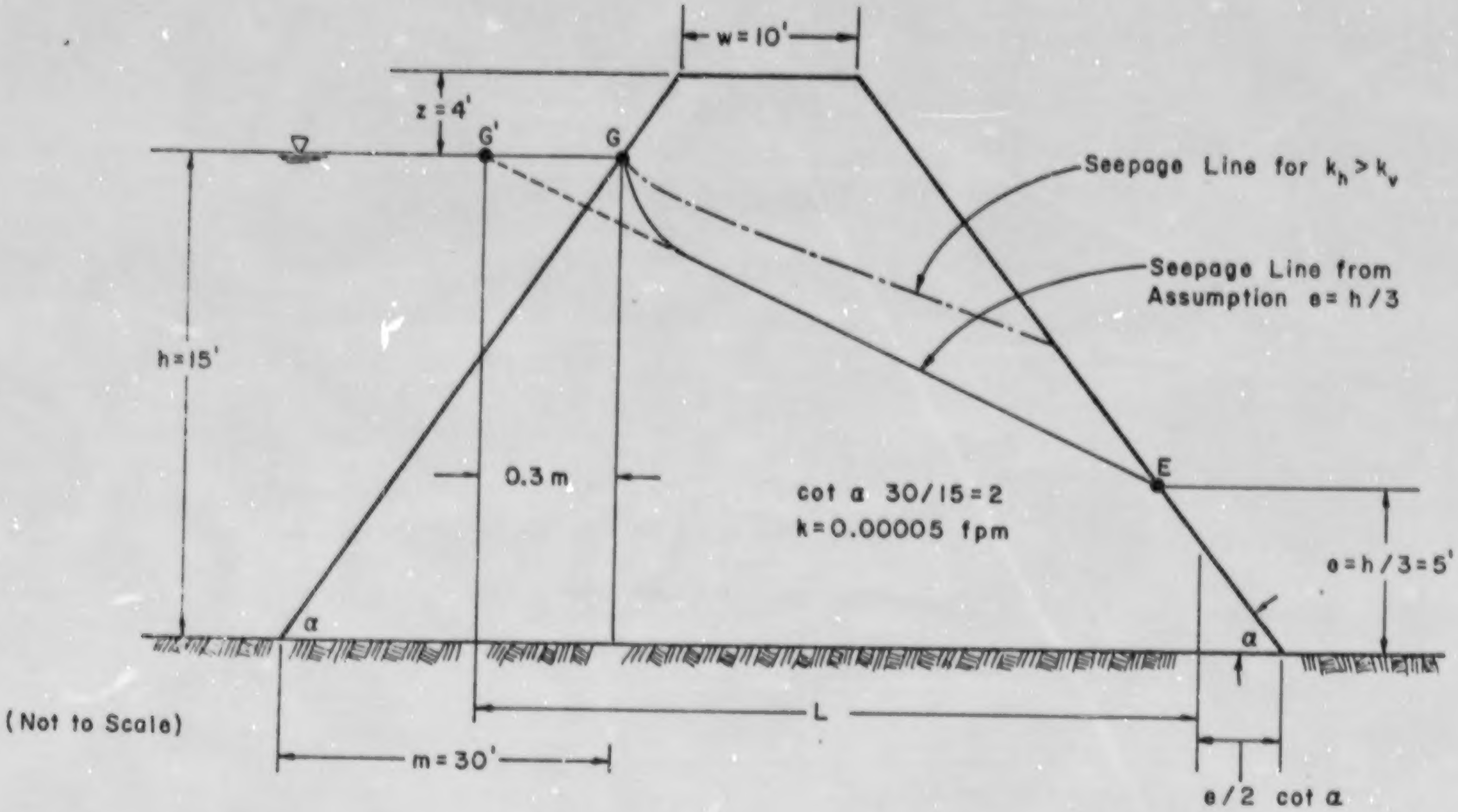

w = 10'
z = 4'
G'
G
Seepage Line for $k_h > k_v$
Seepage Line from Assumption e = h/3
h = 15'
0.3 m
E
cot α 30/15 = 2
k = 0.00005 fpm
e = h/3 = 5'
α
α
L
(Not to Scale)
m = 30'
e/2 cot α

FIGURE A4 - APPROXIMATE METHOD OF SEEPAGE DETERMINATION

	PARTICLE SIZE RANGE				"EFFECTIVE" SIZE		PERMEABILITY COEFFICIENT - k		
	Inches		Millimeters						
	D_{max}	D_{min}	D_{max}	D_{min}	D_{20} in.	D_{10} mm	Ft/yr	Ft/mo	Cm/sec
Derrick STONE	120	36	--	--	48	--	$100x10^6$	$100x10^5$	100
One-man STONE	12	4	--	--	6	--	$30x10^6$	$30x10^5$	30
Clean, fine to coarse GRAVEL	3	1/4	80	10	1/2	--	$10x10^6$	$10x10^5$	10
Fine, uniform GRAVEL	3/8	1/16	8	1.5	1/8	--	$5x10^6$	$5x10^5$	5
Very coarse, clean, uniform SAND	1/8	1/32	3	0.8	1/16	--	$3x10^6$	$3x10^5$	3
Uniform, coarse SAND	1/8	1/64	2	0.5	--	0.6	$0.4x10^6$	$0.4x10^5$	0.4
Uniform, medium SAND	--	--	0.5	0.25	--	0.3	$0.1x10^6$	$0.1x10^5$	0.1
Clean, well-graded SAND & GRAVEL	--	--	10	0.05	--	0.1	$0.01x10^6$	$0.01x10^5$	0.01
Uniform, fine SAND	--	--	0.25	0.05	--	0.06	4000	400	$40x10^{-4}$
Well graded, silty SAND & GRAVEL	--	--	5	0.01	--	0.02	400	40	$4x10^{-4}$
Silty SAND	--	--	2	0.005	--	0.01	100	10	10^{-4}
Uniform SILT	--	--	0.05	0.005	--	0.006	50	5	$0.5x10^{-4}$
Sandy CLAY	--	--	1.0	0.001	--	0.002	5	0.5	$0.05x10^{-6}$
Silty CLAY	--	--	0.05	0.001	--	0.0015	1	0.1	$0.01x10^{-4}$
CLAY (30 to 50% clay sizes)	--	--	0.05	0.0005	--	0.0008	0.1	0.01	$0.001x10^{-4}$
Colloidal CLAY (-2 μ ≥ 50%)	--	--	0.01	10Å	--	40Å	0.001	10^{-4}	10^{-9}

FIGURE A5 - TYPICAL VALUES OF PERMEABILITY COEFFICIENTS
(From Hough, B.K., Basic Soils Engineering)

W = top width of dam, and

α = angle formed by the downstream slope and the foundation surface.

Using Eqs. (2) and (3), the value of e for which q is a maximum can be found by trial and error or by differentiation, but for side slopes flatter than 1:1, the approximation e equal to h/3 is sufficient. Thus, Eq. (2) becomes

$$q = k \frac{h^2 - \frac{h^2}{9}}{2L} = \frac{4\ k\ h^2}{9L} \ . \tag{4}$$

For the example shown in Figure A4, e = 15/3 = 5 ft. The egress point, E, can then be located. Point G' is located a distance 0.3 m from G on the water surface, where m is the horizontal projection of the upstream slope from G to the toe. As shown, the seepage line can then be drawn from G to E. Therefore, G' = 0.3 x 30 = 9 ft from G. Then, from Eq. (3),

$$L = (1.3 \times 15 + 2 \times 4 - 5/2) \times 2 + 10 = 60 \text{ ft.}$$

Finally, from Eq. (2),

$$q = \frac{4 \times 0.00005 \times 15^2}{9 \times 60} = 0.017 \text{ cfm per lineal foot of dam.}$$

This discharge can be converted to any units desired as illustrated in Figure A5.

Occasionally, soils show a difference between their vertical and horizontal permeability. This should be checked during analysis of materials from subsurface investigations. If such a difference exists, a simple technique is used to locate the seepage line. Multiply all the actual horizontal dam dimensions by $\sqrt{k_v/k_h}$, where k_v and k_h are the permeability coefficients in the vertical and horizontal, respectively. Then compute the location of G' and the discharge as before. The results can be rescaled to normal proportions and may look something like the seepage line for $k_h > k_v$ in Figure A4.

Once the seepage line egress and the discharge have been found, a rock toe drain, drainage blanket, or drainage tile can be located at this point to prevent sloughing. The computed discharge can be used to design a drain adequate to carry the expected seepage. Here can be seen an advantage to zoned embankments. The downstream pervious zone can intercept the seepage from any point of egress along the impervious zone. If the pervious material is much larger than the impervious core, it is well to construct a sand and gravel filter between the two zones to prevent internal piping.

This approximate method for locating and computing seepage through an earth embankment has proven quite sufficient for the design of small dams. For a more thorough discussion of seepage, a text of soil mechanics should be consulted.

LITERATURE

Albertson, M. L. and G. R. Fiala. 1960. The Manifold Stilling Basin. Civil Engineering Department. Colorado State University. Fort Collins, Colorado.

Casagrande, A. 1937. Seepage Through Dams. J. New Eng. Water Works Assoc.

Cedergren, H. R. 1967. Seepage, Drainage, and Flow Nets. Wiley and Sons, Inc.

Davis, C. V. 1942. Handbook of Applied Hydraulics. McGraw-Hill.

Dreiblatt, D. 1972. The Economics of Heavy Earthmoving. Praeger Publishers.

Justin, J. D., E. P. Creager, and J. Hinds. 1955. Engineering for Dams. Wiley and Sons, Inc.

Hough, B. K. 1969. Basic Soils Engineering. Ronald Press Co.

National Resources Committee. 1939. Low Dams; A Manual of Design for Small Water Storage Projects. U.S. Government Printing Office, Washington, D.C.

Schwab, G. O. 1966. Soil and Water Conservation Engineering. Wiley and Sons, Inc.

Sherard, J. L. et al. 1963. Earth and Earth-Rock Dams. Wiley and Sons, Inc.

Simons, D. B., M. A. Stevens, and F. J. Watts. 1970. Flood Protection at Culvert Outlets. Prepared for Wyoming State Highway Department.

United Nations, ECAFE. 1958. Proceedings of the Third Regional Technical Conference on Water Resources Developmnet. Flood Control Series No. 13. Bangkok.

United Nations, ECAFE. 1961. Earthmoving by Manual Labour and Machines. Flood Control Series. No. 17. Bangkok.

United Nations, ECAFE. 1962. Proceedings of the Regional Symposium on Dams and Reservoirs. Flood Control Series No. 21. New York.

U.S. Bureau of Reclamation. 1948. Treatise on Dams. Denver, Colorado.

U.S. Bureau of Reclamation. 1973. Design of Small Dams. Second Edition. U.S. Government Printing Office. Washington, D.C.

U.S. Soil Conservation Service. 1969. Engineering Field Manual.

EXPERIMENTAL WATERSHEDS

John N. Fischer[1]

INTRODUCTION

The use of experimental watersheds as a means of studying the natural environment has had impacts on the research in a wide variety of fields, e.g., hydrology, biology, forestry, climatology, and others. Primary objectives in the studies have been in two areas: (1) the use of the watershed as a unit for data collection and (2) the use of the watershed for planning and prediction (Ward, 1971). The successful completion of watershed experiments requires painstaking planning and a thorough understanding of closely related physical processes. First, the experiment must be designed to satisfy a specific objective. Then the watershed itself must be carefully selected, instruments located with precision and method of data analysis considered. Many experiments, otherwise well planned, end in failure due to a lack of consideration of one of these aspects.

Basic data is needed on the relationship of the physical variables to each other and how these relationships are altered by land use changes such as increased use of the watershed for rangeland, cultivation or urbanization. This paper will discuss the objectives and methodology of experimental watersheds and their role in the collection of hydrologic data.

OBJECTIVES OF WATERSHED EXPERIMENTATION

Rainfall-Runoff Studies

Perhaps the most common of all watershed experiments is that which correlates runoff to rainfall. The runoff figure can be utilized to plan flood control structures and predict water supply for irrigation. Also, as Weitzman and Reinhart (1957) state, "A knowledge of the relationship between rainfall and runoff for each season of the year is one of the key factors in planning for an adequate water supply." The information, then, is of considerable importance and since both of these sets of data are relatively easy to collect and analyze, rainfall-runoff studies frequently represent the initial effort in new watershed studies.

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It should be recognized, however, that factors other than the quantity of rainfall may influence runoff. Precipitation intensity and the location of the storm center over the watershed may play a bigger role in the magnitude and timing of runoff than the precipitation depth and watershed parameters themselves. This is particularly true when intense summer convective storms such as described by Drissel and Osborn (1968) are the precipitation source.

Flood Investigation

Studies of flood frequencies are a second objective of watershed experiments. The problems caused by flooding have increased in recent times due to man's encroachment onto flood plains and removal of watershed vegetative cover. Small watersheds are well-suited for flood research for, although they generally produce greater flow per unit area than large watersheds, their smaller contributing area produces lower total flow, even in flood, which reduces hazards to experimenters and instrumentation.

Flood studies normally make use of the unit hydrograph, an analysis technique developed by Sherman (1932) and applied to small watersheds by Brater (1939). One limitation of this technique is that it does not consider individual watershed parameters. Efforts have been made to increase its flexibility, but inevitably, researchers have begun to investigate situations in which use of the unit hydrograph is not applicable. Renard and Keepel (1966) in research conducted in Arizona and New Mexico, found that rainfall producing runoff frequently occurs over only part of the watershed. Conventional unit hydrograph techniques are not well suited for use under such circumstances. The authors state that because of large infiltration losses through stream beds "...flood routing methods must be modified to consider transmission losses and abrupt translatory waves."

Computer simulation techniques are replacing the unit hydrograph in flood investigations due to the over-simplified nature of the unit hydrograph approach. The high speed iteration capability of the computer allows the mathematical generation of a volume of surface runoff, the subsequent routing of the runoff to the stream channel, and a predicted flood hydrograph. Watershed parameters may be (and in fact, must be) incorporated into the computer program allowing this technique to overcome the prime restriction of the unit hydrograph.

Studies of Vegetation Influences

One common watershed experiment involves the study of vegetation influences upon the hydrologic characteristics of the basin. This type study can be divided into three broad categories: (1) those concerned with the hydrologic differences of watersheds under different vegetative cover, (2) those involving the manipulation of vegetation and subsequent observation of changes in basin hydrology, and (3) those considering the hydrologic impact of land use changes on the basin (Ward, 1971).

In research on basins under different types of vegetation, comparative watershed studies are most commonly used. For example, adjacent watersheds, one with shrub or herbaceous vegetation and the other with grass cover, can be instrumented and analyzed to ascertain differences in runoff from the same precipitation event. Similar studies may be carried out to compare differences in forested and non-forested watersheds or between watersheds with different species of forest cover (Ursic and Thames, 1960).

Vegetation manipulation is receiving increased attention currently in the southwestern United States as a means of augmenting watershed runoff. Consequently, many experimental watersheds have been established in this area to determine what changes (primarily in runoff) can be expected from removal of all or part of the vegetative cover (Thorud and Ffolliott, 1974). Generally, in this type experiment, paired watersheds are calibrated to ascertain their before-treatment reaction to precipitation events. After calibration has been accomplished, one of the watersheds is treated. Differences in actual runoff on the treated watershed from that predicted from the calibration data may be attributed to treatment effects.

Water Quality Monitoring

Determination of the effects of land use on the quality of water emanating from a watershed is yet another major objective of watershed experiments. For example, researchers may wish to know what effect the use of an insecticide on a watershed will have on the quality of water emerging from the area. Past data on water quality may be reviewed if available, but if it is not, a calibration period will be necessary. Then as the insecticides are applied (and for an appropriate period thereafter), data can be collected which will provide indications of insecticide influence on the water quality.

Similar experiments may be accomplished to study changes in water quality due to any variety of land use changes. For example, water quality is carefully monitored by the U.S. Forest Service for use as a guide in the use of forest harvesting and silviculture techniques. The National Forests of the United States are areas of multiple use, i.e., in addition to forestry, recreation, mining, and other interests affect the decision-making process. The Forest Service, therefore, must be aware of any degradation of water quality (primarily increases in sediment) which might result from their activities on the watersheds. Experimental watersheds are the common tool employed by Forest Service researchers in their investigations.

Other Objectives

It should be clear from the foregoing discussion that there are a multitude of objectives which may warrant the establishment of experimental watersheds. In addition to those already discussed, a fundamental benefit obtained from such research is the data made available for basic research studies. Hydrologic and meteorologic data will be augmented but also, if the watershed is properly selected and controlled, it can provide observational and experimental opportunities for biologists, geologists, foresters, ecologists, etc. In fact, a whole spectrum of scientific endeavor can be accomplished on a single well-managed experimental watershed.

RESEARCH METHODS IN HYDROLOGY

Boughton (1968) has divided hydrologic research methods into two categories, observational and experimental. Observational data collection methods are defined as those in which the observer plays a passive role, i.e., he observes the behavior of different watersheds and attempts to deduce by analysis the influence of watershed characteristics on land use on the observed variable, usually runoff. Observational methods include plots, unit source areas, barometer watersheds, representative basins and benchmark basins.

Experimental research methods are those in which the experimenter introduces a deliberate change to some part of the watershed and then attempts to monitor the effects produced by the alteration. Boughton discusses three experimental methods which are simply variations of the use of experimental watersheds, i.e., the first uses a single basin, the second, paired basins, and the third, multiple basins.

Single Basins

The technique involved in a single basin experimentation is straightforward. A basin is calibrated for a number of years (calibration period length will be discussed in a later section of this paper) until its behavior during a hydrologic event can be predicted from its past performance; then a treatment is applied. Changes in basin response to precipitation events can then be analyzed to see if they may be attributed to the treatment.

One problem with the single basin method is that once the experiment has been introduced on the watershed, no "control" is left and the researcher must rely completely upon the validity of his calibration data. In a sense, success or failure of this method depends on the ability to predict the behavior of the watershed from climatic variables.

Paired Watersheds

When two basins are used, the experimental method is referred to as paired watersheds. By calibrating both watersheds and then applying a treatment to only one (leaving the second as a control), the weakness of the single basin technique is overcome.

In the paired watershed method, two watersheds are selected for similarities in their physical characteristics, e.g., shape, size, topography, vegetative cover, aspect, location, and land use. They are then calibrated for a period of years to establish their individual responses to precipitation events. The calibration period must be long enough so that the behavior of one watershed can be predicted from the behavior of the other.

After the calibration period, a treatment is applied to one watershed and the other is left as a control. Deviations from expected performance of the treated watershed are attributed to effects of the treatment. Predictions of expected behavior are based on the control watershed but data from the calibration period may also be used for this purpose.

Multiple Watershed Experiments

Multiple watershed experiments have been carried out in South Africa (Wicht, 1965) in efforts to improve upon the paired watershed technique. Generally, it has been found that the increased time and costs necessary to instrument the watersheds and to analyze the data are not justified by the results.

EXPERIMENTAL WATERSHEDS

Selection of Basin

There are several factors which must be considered in the selection of a basin to be used as an experimental watershed. One of the most important requires the determination of the physical characteristics of the basin such as vegetation, soils, geology, aspect, topography, etc. Analysis is made easier by the homogeneity of these parameters. Other considerations include the depth of soil. Deep soils with high permeability will mean that infiltration rates will be great, the storage capacity large, and runoff response to precipitation events smaller and less frequent. Shallower soils of a different texture would give another response entirely to a similar event.

Basin geology should be taken into consideration. Frequently the bedrock does not conform to the topographic features of the basin. Considerable leakage could, therefore, occur which would make data analysis, especially in water balance investigations, difficult. Also in the consideration of topographic features, it is necessary to be able to accurately determine basin boundaries. Easy determination of boundaries is one of the reasons that mountain watersheds have been so popular in this type research. Basins with less relief may be just as suitable for experimentation, however, if care is taken in the determination of boundaries.

Another factor in watershed selection, if the paired or multiple watershed technique is to be used, is aspect. The exposure of the basins must be as similar as possible. Also, in mountainous regions, basins with areas which might be very sunny or very shady simultaneously should be avoided since the moisture conditions of the two areas would be quite different and analysis would be difficult.

Size of the watersheds selected is an important criteria. Hore and Ayers (1965) suggested basins ranging from 10 acres to 25 sq. miles (4 to 6500 hectares) in size. Others recommend smaller or larger areas depending upon the purpose of the experiment and topography of the region. Generally, larger basins are used for water balance studies while smaller areas are necessary when homogeneity in soils or vegetation is a requirement.

Accessibility of the watershed is yet another factor that must be considered during basin selection. Instruments have to be transported to the site and then maintained and monitored in all seasons of the year. Heavy snowfalls or flooding rivers are two obstacles which may hinder or prevent instrument monitoring. The use of telemetry is becoming more common to overcome the problem of difficult access, but it is not inexpensive technology. The researcher is normally better off in the long run selecting watersheds to which he has easy access in all seasons of the year.

In addition to physical factors, there are institutional considerations such as current ownership and land use which must be weighed. A variety of land uses is an advantage when basic research, such as a water balance study, is to be undertaken. In the case of research with a specific objective, such as vegetation modification, a single vegetation type and/or land use would be more suitable. Since experimentation on watersheds almost always involves eventual alterations of basin vegetation or hydrology, it is essential that the experimental watershed be wholly owned or leased for the experiment duration.

Finally, it is a distinct advantage to select an area for which hydrologic data is already available. Historical data makes calibration of the watersheds an easier, and certainly shorter, task. Also, one is able, by reviewing the records, to determine if precipitation events during the experimental period are typical or present an anomoly for the region.

Planning Observations

After the basin has been selected, the research objective should be reviewed to determine what observations need to be made. The most basic is precipitation. Precipitation data may be used to develop precipitation models, estimate precipitation characteristics (time and spatial distribution), determine frequencies, etc.

When precipitation data is recorded with manual gages, visual readings should be taken daily and should not only include the amount but precipitation type and characteristics as well. The data may also be collected by means of recording rain gages which measure the time sequence of the precipitation event as well as the total amount. This type gage may be set to record for variable periods of time; information on precipitation type and characteristics may not be available if long time periods are used and are not accompanied by visual readings.

Gages are placed on the watershed in a network determined in advance to represent an accurate sample of the area. The number, type, and placement of gages depends upon experiment objectives, climate of the region, economics, and access; of these, the variability of precipitation and research objectives are the most important. Precipitation of long duration over large areas is less variable than events of short duration over small areas. Therefore, rain gage density over small areas must be greater. Short duration-small area storms are particularly prevalent in the arid and semi-arid parts of the world. In a study on the Reynolds Creek experimental watershed, an area of 2400 km^2, Neff (1965) found the estimate of the areal mean precipitation to have the following 95% confidence limits:

No. of Gages	95% Confidence Limits
90	± 0.8 in.
30	± 1.4 in.
10	± 2.7 in.
4	± 5.2 in.

A uniform grid network has generally been found superior when absolute estimates of precipitation are required. However, in areas where climatic stress may be expected, such as might be caused by changes in elevation or storm tracks, grid lengths should be shortened. And, as mentioned earlier, grid lengths should be varied with the climate of the area, being shortened in arid areas where precipitation events of large magnitude may occur over very small portions of the experimental area.

A second parameter which is necessary in most watershed experiments is the infiltration rates of the basin soils. As indicated earlier, the permeability and depths of soils on the basin will determine the water holding capacity of the soil, a factor which plays an important role in the runoff response of the basin to a precipitation event. Investigations of soil permeability and a study of geologic records to determine bedrock configuration should be an integral part of any hydrologic study concerned ultimately with a water balance.

Interception observations are normally made when vegetation modification is to be a part of the hydrologic experiment. Conversion of a conifer type cover to grassland, for example, results in a decrease in interception and consequent reductions in interception-related evaporation and sublimation. Interception studies involve complex sampling problems. It is most difficult to determine if snow trapped in a forest canopy is transported from this location by throughfall, evaporation, sublimation, or redistribution.

Data should be obtained on the volume of surface water on the watershed especially in cases where water balances are to be calculated. Surface water includes not only water in lakes and reservoirs but also streamflow and overland flow. Of these, the most important is streamflow since it is an integrated measurement and one of the few hydrologic characteristics that can be measured with any degree of accuracy. It is imperative, therefore, that stream gaging stations be installed accurately with sensitive and stable measuring sections. Observations should be made on a continuous basis with automatic recorders.

In conjunction with surface water measurement, evaporation estimates should be obtained through use of the standard evaporation pan or evaporimeters.

If observation wells are available on the watershed, or if funds are available to drill them, the subsurface water should be monitored. Subsurface water consists of water from the unsaturated and saturated zones. In the unsaturated zone, water is commonly referred to as soil moisture. Its importance is in relation to water balances, evapotranspiration estimation, etc.

In the saturated zone, studies may be implemented to determine groundwater storage and its variation with precipitation events over time. As in the case of soil moisture, data on ground water volume changes in the saturated zone may be used in calculating water balances.

Measuring volumes of subsurface water, either in the saturated or unsaturated zone, is not an easy task and accuracy of data is not usually reliable. It is, therefore, a common practice to lump surface runoff, interflow (unsaturated flow) and the groundwater contribution, measuring them simply as an increase in stream flow.

Runoff plots are frequently used as a means of studying soil erosion. The plot is isolated from the rest of the slope by metal dividers of roughly 0.3 meters in height, half of this extending beneath the surface. Plots vary in size with a common size being approximately 2 meters in width and 3 meters in length. Minimum size is restricted by boundary effects and maximum size by practicality. Runoff and sediment from each plot is collected at the lower end of the plot in barrels or other suitable containers for measurement and analysis.

The determination of water quality parameters may be a research objective of an experimental watershed. Researchers may wish to determine what effect, if any, increasing cattle density on a range will have on runoff quality, for example. Water samples may be obtained at the gaging station either manually or mechanically. Several devices are available commercially for this purpose.

CALIBRATION OF WATERSHEDS

In calibrating watersheds, two or more basins are instrumented with standard hydrologic instrumentation including precipitation gages, stream gaging stations, sediment basins, runoff plots and other equipment to measure desired parameters. The instruments are maintained and data recorded for a period of years prior to any treatment on the watershed; this period is called the calibration period.

During this time, relative reactions of each watershed to various precipitation events in varying sequences may be ascertained. In this way, uncontrolled variation due to climate and other factors not associated with treatments may be minimized through the use of statistical methods. At the end of the calibration period, treatments of one or more of the watersheds are commenced. Data collection is continued until the effects of the treatment have been determined.

It is important to calibrate the watershed for an optimum period of time. Too short a period will make statistical analysis techniques difficult to use while calibration periods of excess length cause losses in time and money.

Researchers have developed several methods to determine optimum length of the calibration period (Wilm, 1949; Reinhart, 1967). Wilm considers it appropriate to have periods before and after treatment of equal length, thereby giving equal opportunity for exposure to variations in climate and other factors. In practice, however, the period following treatment is usually longer than the calibration period because valuable data may be obtained from the treated watershed for a longer time than just the length of the calibration period.

At the end of calibration, weather records of the period should be compared with historical weather data to insure that a full range of probable events has been encompassed. If this has not occurred, consideration must be given to extending the calibration period to at least include the type of weather events of particular interest.

One problem associated with watershed experiments is that they take a long time to complete. Bethlahmy (1963) has suggested a method for shortening the calibration period based upon comparative watershed reaction to the same storm. His technique involves (1) the change in stage or flow from the time the hydrograph starts to rise until the peak is reached, and (2) the elapsed time for period of rise. The author states that the advantage gained will depend on the increase in number of degrees of freedom and the relative degree of correlation (between the control and treated watersheds) of storm response and annual flow.

Event-by-event analysis of precipitation events instead of the more conventional year-by-year method seems particularly appropriate in arid and semi-arid regions. In these areas, years may pass between precipitation events, the calculation of meaningful precipitation means is difficult, and the return periods are large for all storm sizes, the latter necessitating lengthy calibration periods and experiment duration. Under these conditions, event-by-event analysis, as suggested by Bethlahmy, has obvious advantages.

FUNDAMENTAL PROBLEMS OF WATERSHED EXPERIMENTS

The experimental watershed technique has been criticized by some researchers (Slivitzsky and Hendler, 1964; Ackerman, 1966). Specifically, the critics argue that: (a) experimental watersheds are unrepresentative, (b) it is difficult to transfer results from the experimental watershed to other watersheds, (c) it is a costly experimental technique, (d) they frequently leak, and (e) the changes induced are often too small for detection.

The most serious charge is that small watershed experiments are unrepresentative and it is difficult to transfer results of experiments on them to larger areas. The criticism results from the frustration of planners who have tried to apply the results of experimental watershed research to large river basins under the assumption that the small watershed is a microcosm of a larger system. But small upland watersheds are only subsystems within the overall river basin system. As has been mentioned, one of the prime criteria for selection of the small watershed is the homogeneity of its physical properties. Therefore, they should not be expected to typify the larger inhomogeneous watershed composed of many such subsystems.

Despite this limitation, some satisfactory results have been obtained by assuming that the smaller unit is, in fact, representative of the larger basin. Sopper and Lull (1965) in a study of 137 small watersheds found that within major physiographic units there were "evident similarities in streamflows from small watersheds and much larger watersheds, as represented by mean values for the entire physiographic unit."

Transferring research results from a small watershed to a larger one of which the first is a subcomponent is therefore possible, but the researcher must remember that inhomogeneity can cause inaccuracies in the extrapolation. Transferring results to another basin or to another geographic or climatic area presents even greater hazards. Only the most general conclusions should be expected to be verified under these circumstances. For this reason, small watershed experiments reflecting varying activities on local watersheds should be a part of the research effort in each geographic region of the world.

In the past, many watershed experiments have been poorly conceived and hastily planned, leading frequently to losses in time and money. It is stretching the point, however, to generalize that the technique is too expensive, especially in the absense of rigorous cost-benefit analysis. Time is a major cost factor. Calibration periods are generally five years or longer. Some studies (Hewlett, 1966; Swank and Miner, 1968) have shown, however, that calibration periods as short as three years give useful information if the treatment period is longer. In addition, once a watershed has been gaged, short-term interim studies can be superimposed at considerably less cost and they should yield more information than if conducted independently.

The criticism that watersheds leak is valid, and, moreover, there is no certain method for determining the amount of leakage. To confront this problem, watershed researchers should be advised to avoid experiments on water yield in complex glacial drift, karst terrain, in tilting strata containing interbedded aquifers or aquicludes, or on undefined watersheds having surface and subsurface catchment areas differing by 10% or more (Hewlett, Lull, and Reinhart, 1969). These few restrictions leave many opportunities for researchers to locate experimental watersheds for the study of treatment effect on the timing and volume of water yield.

Finally, we must treat the criticism that small changes are difficult to identify. An inherent advantage in paired watershed experimentation is that the difference in approach may be used in making the detection of small changes easier. Johnson and Kovner (1956) report that differences in stream flow of 5 and 10 percent have been detected at high confidence levels.

Nevertheless, present statistical analysis techniques are frequently not able to identify small changes and attribute them to treatment. Treatments are generally selected, therefore, from which a substantial effect on water yield or other desired measurement may be anticipated.

In spite of the shortcomings discussed, Wicht (1966) states that experimental studies "are indispensable to the complete understanding of catchment management effects as demonstrated by catchments experiments." Even with a more complete understanding, however, the circuitous argument of the uniqueness of individual watersheds must still be faced, and, thus, the empiricism of experimental watershed research must still be relied upon. In fact, Ackerman, one of the severest critics of this technique, states that "we still need and, infact, have no alternative to conducting small watershed research" (Ackerman, 1966). It seems apparent that if we wish to manage watersheds, we must study them.

ANALYSIS OF DATA

Analysis of data from experimental watersheds may consist of simple comparison studies of runoff, such as volume, peak rate, seasonal distribution, flow duration, etc. Other more exact methods include the use of statistical analysis.

Statistical methods may be graphical or involve single variable and multivariate analysis. These are used to test the significance of differences between data obtained prior to experimental treatment and that obtained after treatment.

Double-mass plots are the most commonly used method of graphical analysis. The technique consists of plotting the cumulative runoff of one plot against that of another. Changes in runoff due to land use changes can be detected by this method.

It should be recognized, however, that graphical analysis serves only to supplement statistical analysis. It is best used in preliminary analysis or for illustration. There is a statistical equivalent for most graphical methods through the use of which a numerical value may be assigned to various graphical deviations, thereby yielding information of a more exact nature.

Examination of a single variable is a common analysis method in land use change studies. A variety of variables may be analyzed but some runoff associated variable, such as annual volume or seasonal runoff, is usually chosen. One problem associated with land use change studies is that natural variation is great, and it is frequently difficult to attribute changes in runoff simply to the effect of the land use treatment.

In observation-type experiments, the most common analysis method is multivariate analysis. Corelations are sought between data collected for the various variables. Multiple linear regression, making use of digital computers, is the most common analysis technique in this case.

Watershed Models

Watershed models may be devised to simulate the physical processes on the basin. The models have two major components--one to maintain a water balance and the other to route the runoff from the basin to the channels and on to the gaging station.

In actuality, the model is a series of mathematical relationships describing changes in physical parameters such as infiltration rates, evaporation, etc. over time. The input is precipitation and the output is generally runoff. The equations are connected by means of a digital computer program which carries forward the water balance and routing.

The first and still the most prominent of the watershed models, presented by Crawford and Linsley in 1962, is known as the Stanford Watershed Model. It has served as the basis for others (Huggins, et al., 1973) to do additional research in attempts to more accurately simulate watershed behavior.

Simply by changing the values of physical parameters, watershed models may be modified to simulate any type of watershed. This represents a clear advantage over experimental watersheds from which results are very difficult to transfer, as has been discussed. Another advantage of the models is the time which may be saved through their use. In a very short time, the effects of any variety of watershed treatments may be simulated by adjusting model parameters to represent the new anticipated conditions on the watershed, whereas on an experimental watershed only one treatment may be applied and ten years may be necessary to judge the effects.

The difficulty with simulation models at this point is that most of them do not predict treatment effects accurately enough. They are based upon the estimation of the physical parameters and mathematical relationships; opportunities for inaccurate estimation or misapplication of equations abound. Considerable time and effort must yet be spent before the models replace experimental watersheds as the principle method of predicting treatment effects and simulation can never be expected to eliminate the need for well-planned physical experimentation on watersheds.

SUMMARY

Experimental watersheds may be employed to satisfy a variety of research objectives. While most commonly used to demonstrate the relationship between runoff and some human activity on the watershed, other objectives, such as flood investigation, water quality monitoring, and basic research studies, may also be satisfied.

Hydrologic research methods, in addition to watershed experimentation, include plots, barometer watersheds, and unit source areas among others. None of these presents the versatility of the experimental watershed technique. Watershed experiments may consist of one, two, or more watersheds. Of these, the use of two watersheds is the most popular.

Many factors should be considered in the selection of experimental watersheds. Homogeneity of physical parameters over the watershed makes for simpler statistical analysis. Other important considerations include the size of the basin, land use, ownership, and accessability.

Observations are made according to the research objective. Common parameters measured are precipitation, interception, evaporation, erosion, sedimentation, and runoff. Of these, precipitation is the only one that is not altered by common experimental objectives, although in some cases, it too may be manipulated.

The calibration of watershed experiments consists of a period of years prior to the experimental treatment during which the reaction of the watershed(s) to precipitation events is carefully recorded. The length of time devoted to calibration is important for too long a period will increase costs

unnecessarily, and too short a period can make data analysis difficult. Generally, a minimum period of 3 to 5 years is recommended. The duration of the experiment after treatment is dependent upon cost considerations, land ownership, and experimental objectives.

The experimental watershed technique has been criticized for several reasons. Primary among these is the charge that they frequently are unrepresentative and it is, therefore, difficult to apply research results to other watersheds. It has also been charged that subterranean leaks are impossible to quantify thereby reducing the value of water balance data.

While there is some validity in the criticisms, it is also true that the technique has provided the basis for much of our present understanding of the science of watershed management. Recently developed watershed simulation models based upon the use of digital computers present alternatives to experimental watersheds. However, simulation is no substitute for physical experiments on the watersheds themselves. Experimental watersheds present the integrated and final result (in runoff) of a change in land use on a hydrologic basin. For this reason, they will continue to play an important role in hydrologic investigations.

LITERATURE

Ackerman, W. C. 1966. Guidelines for Research on Hydrology of Small Watersheds. Office of Water Resources Research, 26 pp.

Bethlahmy, N. 1963. Rapid Calibration of Watersheds for Hydrologic Studies. Int'l. Assoc. Sci. Hydrology Bulletin 8:38-42.

Boughton, W. C. 1968. Research Methods in Land Use Hydrology. Water Resources Bulletin (2):34-44.

Brater, E. F. 1939. The Unit Hydrograph Principle Applied to Small Watersheds. Amer. Soc. Cir. Eng. Proc. 65:1191-1215.

Crawford, N. H. and R. K. Linsley. 1966. Digital Simulation in Hydrology: Stanford Watershed Model IV. Tech. Rpt. No. 39, Eng. Dept., Stanford Univ., Palo Alto, California.

Dowdle, H. J. 1965. Planning Water Management for a Small Watershed. Hydrologic Activities in the S. Carolina Region: Proc. Conf. March 17-18, 1965. (South Carolina, Clemson Univ.), 7-10.

Drissel, J. C. and H. B. Osborn. 1968. Variability in Rainfall Producing Runoff from a Semi-Arid Rangeland Watershed, Alamogordo Creek, N.M. J. Hydrol. 6:194-201.

Hewlett, J. D. 1966. Will Water Deman Dominate Forest Management in the East? Proc. Soc. Am. Foresters, Seattle, Wash. 154-159.

Hewlett, J. D., H. W. Lull and W. G. Reinhart. 1969. In Defense of Experimental Watersheds. Water Resources Research, 5: 306-316.

Hore, F. R. and H. D. Ayers. 1965 Objectives of Research Watershed Programs, Research Watersheds. Proc. Hydrol. Sympos. No. 4, Univ. of Guelp, Ontario: 5-10.

Huggins, L. F., J. R. Burney, P. S. Kundu and E. J. Monke. 1973. Simulation of the Hydrology of Ungaged Watersheds. Tech. Rpt. No. 38 Water Res. Res. Center, Purdue University, Lafayette, Ind.

Johnson, E. A. and J. C. Kovner. 1956. Effect on Streamflow of Cutting a Forest Understory. For. Sci, 2: 82-91.

Khaskina, M. I. 1963. Forecasting the Flow of Flood Water of the Dneiper River at Kiev Based on the Flow of Small Rivers. Soviet Hydrology, 25-34.

Neff, E. L. 1965. Principles of Precipitation Network Design for Intensive Hydrologic Investigations. WMO-IASH Symp. on Design of Hydrometeorological Networks, Quebec.

Reinhart, K. G. 1967. Watershed Calibration Methods. In "Int'l Symp. of Forest Hydrology," ed. W. E. Sopper & H. W. Lull. Pergamon Press, Oxford. pp. 715-723.

Renard, K. G. and R. V. Keppel. 1966. Hydrographs of Ephemeral Streams in the Southwest. J. Hydraul. Div., A.S.C.E., 92 (No. HY2): 33-52.

Sherman, L. K. 1932. The Relation of Hydrographs of Runoff to Size and Character of Drainage Basins. T. A. G. U., 13: 332-339.

Slivitsky, M. S. and M. Hendler. 1964. Watershed Research as a Basis for Water Resources Development, Research Watersheds: Univ. of Gueiph, Ontario. Proc. 4th Hydrol. Sympos. 289-294.

Sopper, W. E. and H. W. Lull. 1965. The Representativeness of Small Forested Experimental Watersheds in Northeastern United States. I. A. S. H. Pub. 66, Sympos. de Budapest, 2: 441-456.

Swank, W. T. and N. H. Miner. 1968. Conversion of Hardwood-Covered Watersheds to White Pine Reduces Water Yield. Wat. Res. Res., 947-954.

Thorud, D. B. and P. F. Ffolliott. 1974. Vegetation Management for Increased Water Yield in Arizona. Univ. of Arizona Tech. Bull. #215, Tucson, Az.

Toebes, C. and V. Ouryvarv. 1970. Representative and Experimental Basins, UNESCO. Henkes-Holland, Haarlem.

Ursic, S. J. and J. L. Thames. 1960. Effect of Cover Types and Soils on Runoff in Northern Mississippi. J. Geophys. Res., 65: 663-667, 1960.

Ward, R. C. 1967. Design of Catchment Experiments for Hydrological Studies. Geographical Journal, 133: 495-501.

Ward, R. C. 1971. Small Watershed Experiments, University of Hull. Occasional Papers in Geography No. 18.

Weitzman, S. and K. G. Reinhart. 1957. Water Yields from Small Forested Watersheds. J. Soil & Water Conservation, 12: 56-59.

Wicht, C. L. 1966. Summary of Forest Evapotranspiration Session. In ed W. E. Sopper and H. W. Lull, Forest Hydrology, Pergamon Press, 491-494.

Wilm, H. G. 1949. How Long Should Experimental Watersheds be Calibrated? Trans. AGU 30: 272-278.

EXPERIMENTAL WATERSHED INSTRUMENTATION

John L. Thames[1]

The fundamental unit of water resource management is the watershed. A watershed can be variously defined as (1) a river basin which contributes water to a particular channel or a set of channels, (2) a catchment area for the precipitation provided to stream channels, (3) a unit of the earth's surface where basic climatic quantities can be isolated and measured.

Biologists, ecologists, and biogeographers have turned to the watershed as an ideal unit in which to develop the ecosystem approach. Systems engineers and economists view the watershed as the basis for study and development in terms of river basin planning for economic development. Hydrologists and engineers consider the watershed a system within which a balance can be struck between inflow and outflow of water and energy. The watershed manager must be concerned with all these concepts.

The term watershed implies a domain within boundaries. The boundaries may be physical such as watershed divides or defined by processes such as the runoff process. The watershed domain may be divided further into subcomponents of smaller watersheds or into subprocesses such as overland flow. Watersheds may be controlled with physical structures such as the series of dams operated by the Tennessee Valley Authority or uncontrolled as are most natural watersheds. The watershed manager must work with both.

The watershed manager may be called upon th exercise control over a watershed to meet some objective by applying an upstream treatment. This might involve selecting an appropriate cover type, harvesting method, or plant cover management system. His objectives may be to increase water yields, provide a dependable supply of water for downstream use, improve forest and range production on the watershed, maintain a specified standard of water quality, reduce erosion and flood hazard, enhance recreation and wildlife, or some combination of all of these. He may have to consider the feasibility of reservoirs in combination with upstream watershed treatments.

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Experimental watersheds have traditionally been a fundamental research tool and testing ground to provide the information and understanding necessary to carry out watershed management programs. Much of what is known on management of lands to influence the quantity, quality, distribution and timing of water for human needs is the result of research with experimental watersheds.

This paper is concerned with the instrumentation of experimental watersheds and is confined to the measurement of the two most important factors, i.e. input (precipitation) and output (runoff).

INPUT (PRECIPITATION)

The measurement of precipitation forms an integral part of most hydrologic studies. Information on precipitation--amount, intensity, type, frequency, duration--is essential in much of the research in land mangement. Although a wide variety of gages have been developed, the basic method of making measurements has remained unchanged since 1400, when rain gages--similar to those now in use--were first used in Korea. The major problems have usually been to make point measurements accurately and to extrapolate point values to areal estimates. The following summarizes information on the measurment of precipitation--primarily rainfall-on experimental watersheds.

Types of Gages (Point Measurements)

Three types of precipitation gages are now in general use: (1) the standard gage--size varies with standards established in individual countries--(usually read after each storm event or at relatively short predetermined time intervals); (2) the storage gage (manufactured in several sizes and read only periodically); and (3) the recording gage (records rate of precipitation as well as depth).

It has been shown that over a 16-year period the difference in rainfall catch between a standard gage and a weighing-recording gage was less than 0.05 percent. Properly exposed, calibrated, and evaluated, the 8-in. diameter weighing rain gage yields hourly precipitation values with standard error of about 0.01 in. so that reliability within 0.02 may be assumed.

Gages with several different orifice diameters seem to measure rainfall with about the same degree of accuracy. It has been found that rain gages with orifices 2 to 24 inches in diameter do not vary by more than 1 or 2 percent in accuracy of measurement.

Errors in Point Measurement of Precipitation

The most common factors that affect the accuracy of rain gage catch are evaporation, adhesion, color, inclination, splash, wind, faulty technique in measuring gage catch, and damage to the gage. (Table 1)

Table 1. Approximate Errors in Precipitation Measurement. (from Kurtyka, 1953)

Factors	Percent Error
Evaporation	-1.0
Adhesion	-0.5
Color	-0.5
Inclination	-0.5
Splash	+1.0
Subtotal	-1.5
Exposure	-5.0 to -80.0

The effects of wind are due primarily to an increase in pressure on the windward side of the gage, a decrease in pressure and a marked acceleration of wind over the top of the gage, and eddy currents over and within the orifice. As wind speed normally increases with height, the higher the collector is placed above the ground the greater will be the error due to wind effect.

Table 2. Effect of Gage Height on Rainfall Catch

Height Above Ground (cm)	2	4	6	8	100	500	2000
Rainfall (mm)	105	103	102	101	100	95	90

The catch of an unshielded 8-in. gage, even when only moderately exposed to the wind, is about 5 percent less than the true precipitation.

Improving the Accuracy of Point Measurements

To correct the errors due to wind turbulence, several types of windshields have been developed. The most notable of these are the Nipher and Alter shields. Windshields are designed to divert the flow of air down and around the rain gage to eliminate updraft in the region of the orifice, thus placing it in an undisturbed flow of air.

The relative effectiveness of the Alter and Nipher shields has been investigated on a total catch basis. The general consensus is that the Nipher shield was superior for reducing wind errors. (Table 3)

Table 3. Effect of Shielding.

Wind Velocity (m.p.h.)	Percent Increase in Shielded Gage Catch	
	Rain	Snow
0-30	4	34
30-75	40	69
> 75	42	300

The pit gage probably gives the most accurate measurements of rainfall at a point. When the rain gage is placed in a pit with its orifice level with the land surface, any deleterious wind effects on the gage are diminished. However, pit gages are inadequate for snow measurement. And for extensive rain gage networks, the increased accuracy may not warrant the additional cost of installing and maintaining pit gages.

Selection of Raingage Sites

Three general types of natural parameters which affect the variation in amounts of precipitation over an area are: (1) weather itself, in terms of areal distribution of condensation processes and types of circulation of and within storms; (2) topography of a scale large enough to affect the weather; (3) smaller scale terrain effects which influence the performance of the gage. The selection of a gage site, which is representative of the surrounding area, will be influenced primarily by factor (3).

Local anomalies in the rainfall pattern may be produced by small-scale topographic influences or by obstructions which distort the wind pattern in the immediate vicinity of the gage. This distortion may make the particular gage site nonrepresentative of the general region, introducing an error in the areal determination. In regions of flat topography, this factor is usually of minor importance. In mountainous terrain, it may account for much of the variation in precipitation measurements. Variation in precipitation may be attributed in some cases to variations in the local exposure of gage sites rather than in actual differences in the distribution of precipitation.

An ideal exposure would eliminate all turbulence and eddy currents near the gage. Individual obstructions, whether a building or a tree, may set up serious eddy currents and, as a general rule, should not be closer to the gage than twice (preferably four times) the height of the object above the gage. When objects are numerous and uniform, such as in a forest opening, their height above the gage should not exceed about twice their distance from the gage.

At exposed sites, compensate for the lack of natural protection by shielding or by using pit gages. The Nipher shield is recommended if the precipitation is primarily rain, the Alter shield if a substantial portion of the precipitation is snow.

Areal Measurements

Fairly wide variations in precipitation exist in areas of level terrain as well as in those of considerable relief. Most of these variations are accounted for by storm type, elevation, aspect, land slope, wind direction, and wind speed.

Assuming that individual records used are reliable, the accuracy of an estimate of areal rainfall seems to depend primarily on the actual range of rainfall within the area, and on the number of records used. For a given number of stations, the accuracy of the average is proportional to the range of variation between the amounts for the different stations.

The fairly wide variations in precipitation, due to storm type or terrain, point out the fallacy of taking the records of one station as representative or typical of large areas. It should also be kept in mind that the sampling area of a standard 8-in. rain gage is only 8×10^{-6} acre in size.

How accurately a point rainfall measurement represents the mean rainfall for areas of varying sizes in the vicinity of the point observation is pertinent to the design of rain gage networks on experimental watersheds and to the interpretation of data.

The number and location of rain gages in an experimental watershed depend primarily on the objectives of the investigation to be undertaken. A frequent objective is to provide an outdoor laboratory where studies in which precipitation is included as a variable in the analyses, i.e. water balance calculation, calibrating a watershed upon itself, runoff and erosion studies, etc. can be made.

Number of Gages Required

An example for locating rain gages in agricultural watersheds ranging in size from 23 to 330 acres is given in Table 4. Considered here are both areal distribution and site exposure requirements for areas with a continental type of climate, where heavy precipitation often occurs as a result of thunderstorms.

The use of random sampling as a means of excluding bias in the selection of gage sites and for estimating the number of gages needed is suggested. Random sampling also lends itself to standardized statistical methods of analyses. However, in areas of dense brush or forest, this type of rainfall sampling may not be practical owing to the difficulty of obtaining adequate sampling sites.

Rainfall variability on a watershed for monthly, seasonal, or annual periods can be estimated at much lower operating cost by using a regular network which is read after each storm event. By reading storage gages monthly or seasonally, the effects of storm types on variability may be lost, but systematic differences in precipitation between parts of the watersheds for these longer periods can be estimated.

Table 4. Measurement of Precipitation on Experimental Agricultural Watersheds.

Size of Drainage Area (acres)	Minimum Number of Rainfall Stations
0 to 30	1
30 to 100	2
100 to 200	3
200 to 500	1 per 100 acres
500 to 2500	1 per 250 acres
2500 to 5000	1 per square mile
over 5000	1 per each 3 square miles*

*This recommendation will often be impractical in watersheds of more than 20 square miles. For these large areas, strive for good distribution with as many rainfall stations as can be properly maintained and serviced.

Methods of Calculating Mean Watershed Precipitation

The mean depth of precipitation over a watershed is required in many types of hydrologic investigations. Several procedures are used in deriving this value. The three most common are the arithmetic, the Thiessen, and the isohyetal methods.

Arithmetic Method -- A straight arithmetic average is the simplest of all methods for estimating the mean rainfall on a watershed. This method yields good estimates in level terrain if the gages are numerous and uniformly distributed. Even in mountainous country with a dense raingage network, arithmetic averages will yield fairly accurate results if the orographic influences on precipitation are considered in the selection of gage sites. However, if gages are relatively few and irregularly spaced and precipitation over the area varies considerably, the arithmetic mean is likely to differ greatly from the results derived by other methods.

Thiessen Method -- This method involves determination of an area of influence for each station. Polygons are formed from the perpendicular bisectors of lines joining nearby stations. The area of each polygon is determined and is used to weigh the rainfall amount of the station in the center of the polygon. The entire area within any polygon is nearer to the rainfall stations contained therein than to any other, and it is, therefore, assumed that the rainfall recorded at that station should apply to that area. The results are usually more accurate than the arithmetic average unless a large number of gages are used. The Thiessen method allows for non-uniform distribution of gages by providing the weighting factor for each gage.

The method assumes linear variation of precipitation between stations and makes no attempt to allow for orographic influences.

Isohyetal Method -- In the isohyetal method, station location and amounts are plotted on a suitable map, and contours of equal precipitation (isohyets) are drawn. The average depth is then determined by computing the incremental volume between each pair of isohyets, adding the amounts, and dividing by the total area. Many investigators indicate this as theoretically the most accurate method of determining mean watershed precipitation. But is is also by far the most laborious.

The accuracy of the isohyetal method depends upon the skill of the analyst. An improper analysis may lead to serious error. If linear interpolation between stations is used, the results will be essentially the same as those obtained with the Thiessen method.

Summary

In evaluating the accuracy of precipitation measurements on watersheds, errors due to (1) failure of the rain gage to represent actual point rainfall and (2) extrapolation of point rainfall to areal values must be considered.

The accuracy with which a gage measures precipitation at a point is influenced by many factors, the most important of which is wind (exposure). Under exposed conditions, wind action on the gage tends to reduce the catch. The precision of point rainfall measurements may be increased by using a Nipher windshield on the gage or by placing the gage in a pit with its orifice parallel to the slope of the ground. Tilted gages have improved the catch of gages at exposed mountain sites, especially when precipitation falls at large inclinations from the vertical. However, they are not recommended unless considerable study is made beforehand.

Fairly wide variations in precipitation have been shown to exist in areas of level terrain as well as those of considerable relief. Most of these variations are accounted for by storm type, elevation, aspect, land slope, wind direction, and wind speed. Enough gages must be used to sample adequately the variations to obtain reliable areal estimates. The average difference between point and areal mean rainfall increases as the storm size increases, and it decreases as sampling time increases. The relative variability tends to decrease as storm mean rainfall increases and as the totalizing period is increased. Standards of accuracy for areal averages should be modified in inverse relations to the size and importance of storms to avoid using an impractically large number of rain gages.

For areas of relatively flat terrain, a uniform distribution of gages is best for determining areal amount and variability of precipitation. In mountainous areas, however, altitude and aspect as well as area must be fully sampled to derive accurate estimates of precipitation over a watershed.

The fairly wide variation in precipitation, owing to storm type or terrain, point out the fallacy of taking the records of one station as representative of large areas. Whether a gage site is representative of an area can be determined only by sampling the immediate vicinity with several gages to obtain a measure of existing variation. To calculate mean basin precipitation on experimental watersheds having well-designed rain gage networks, the Thiessen method is the most expedient to use.

OUTPUT (RUNOFF)

Stream-gaging, as used here, is the measurement of the water leaving a watershed as low in a natural stream channel. Water lost to deep seepage and not appearing as streamflow at the point of measurement cannot be measured by the stream-gaging station. Therefore, watersheds with minimum deep seepage are best for research.

Small watersheds include those of about 20 to 1,500 acres. Such watersheds are small enough so that construction of an artificial control is not impractical. On larger streams, gaging is usually done by using natural controls; such measurement is generally less precise than that with artificial controls on smaller streams.

A control is a natural constriction of the channel, a long reach of the channel, a stretch of rapids, or an artificial structure downstream from a gaging station that determines the stage-discharge relation at the gage.

There are many objectives of stream gaging in watershed research. In some cases, one objective may be paramount; in others, several may be about equally important.

A common objective is a continuous record of streamflow. To attain this goal, recording instruments that give a round-the-clock record are required. Usually yearlong records are obtained, but records for the growing season or some other short period may suffice. Measurements may be made to determine maximum flows and runoff volumes for major storm periods, low flows, or all flow leaving the watershed.

The research program will specify the number of stream-gaging stations required. Ordinarily two or more watersheds, as nearly identical as possible, are chosen. This permits the development during the pretreatment period of an expression for predicting flow of one watershed from that of the other; after treating one of the watersheds, differences between predicted and measured flow indicate the effect of treatment.

The most common types of artificial controls are weirs and flumes. Weirs are often preferred for gaging small watersheds particularly those with perennial flows. Where heavy sediment-laden flows are common, particularly as bedload movement, flumes should be used; a flume is a stabilized channel (without an impoundment) with access to a stilling well. Flumes also must be used where the gradient of the stream is particularly low.

The various objectives for which stream-gaging stations have been built have resulted in many different types of weirs and flumes.

Weirs or flumes are constructed of various materials. Concrete, because of its strength and permanence, probably is used the most. Treated wood, concrete blocks, metal, and many other materials are also used. The weir notch is often a steel blade set into concrete, and flumes are often lined with steel for permanence.

Weirs

As used here, weir includes all components of a stream-gaging station that incorporates a notch control (Fig. 1)

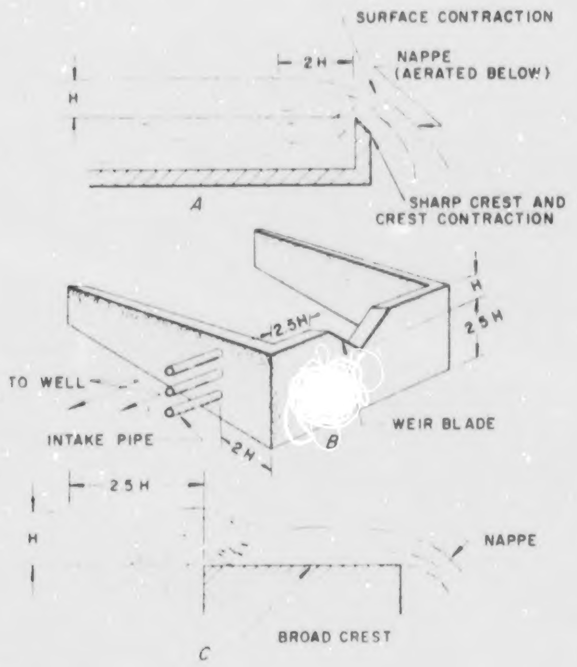

SURFACE CONTRACTION
2 H
NAPPE (AERATED BELOW)
H
A
SHARP CREST AND CREST CONTRACTION
H
2.5 H
2.5H
TO WELL
INTAKE PIPE
WEIR BLADE
B
2H
2.5 H
H
NAPPE
BROAD CREST
C

Fig. 1. Schematic diagrams of general hydraulic relationships for weirs. A, Flow characteristics over a sharp-crested weir; H is the depth of water producing the discharge; B, minimum requirements for proper discharge when H equals greatest expected depth for a sharp-crested V-notch weir with end and crest contractions; C, flow characteristics over a broad-crested weir of rectangular cross-section.

An impoundment of water (the weir basin) is formed upstream from the wall or dam containing the notch. A stilling well with water-level recorder is connected to the weir basin. A gagehouse or some other type of shelter is provided to protect the recorder.

The cutoff wall or dam is used to divert through the notch all water (above or below the streambed) moving down the channel. Where possible, the cutoff wall is tied into bedrock or other impermeable material so that no water can flow under or around it. But where leakage is apt to occur, the weir basin is sometimes constructed as a watertight box.

The edge or surface over which the water flows is called the crest. Weirs can be either sharp crested or broad crested. A sharp-crested weir has a blade with a sharp upstream edge so that the passing water touches only a thin edge and springs clear of the rest of the crest.

A broad-crested weir has a flat or broad surface over which the discharge flows. Broad-crested weirs are generally used where sensitivity to low flows is not critical and where sharp crests would be dulled or damaged by sediment or debris.

The sheet of water flowing over the weir is the nappe. The weir has free discharge if the nappe discharges into the air: air circulates freely on all sides of the flow issuing from the weir notch.

As the nappe flows through the notch, the velocity of flow increases; and the anppe cross section is reduced or contracted. The contraction is affected by the shape of the notch and basin characteristics immediately upstream from the notch.

Where the depth of water from the crest to the basin floor is less than 2.5 times the head of water over the crest, the crest contraction of the nappe is partially suppressed. Velocity of approach will increase, and actual discharge will be greater than that shown by the normally used formulas and tables (Fig. 1).

If the basin is the same width as the crest, the weir has its end contractions suppressed. For complete end contractions, the distance from the edge of the notch to the side of the weir basin or channel should be at least 2.5 times the head being measured. A narrower weir basin or channel results in increased velocity of approach and increased flow for a given head.

For best results, the velocity of approach should be held to a maximum of 0.5 foot per second. Where velocities of approach are appreciable, the discharge should be corrected.

Water discharging over the crest of a weir drops slightly in elevation immediately upstream from the crest. This decrease is caused by the water's acceleration in velocity as it approaches the crest. Such a drop is called surface contraction or drop-down. In sharp-crested weirs, the effect of this surface contraction extends upstream from the crest a distance twice the head of water flowing over the crest. Therefore, the intake to the stilling well should be located upstream from the crest a distance equal to or greater than twice the head of the maximum anticipated flow (Fig. 1). Fully contracted weirs are generally preferred in research.

The rectangular weir has vertical sides and horizontal crest. Its height and width can be varied considerably, depending on the anticipated flow. The ratio of height to width is usually about 1:3 or 1:4. Its major advantage is its capacity to handle high flows. However, the rectangular weir does not provide for precise measurement of the low flows of small experimental watersheds--a small increase in head will give only a slightly increased discharge.

The trapezoidal weir is similar to the rectangular weir. Its sides, of course, are sloped from the vertical. It has a smaller capacity than a rectangular weir of the same crest length; the discharge is approximately the sum of discharges from the rectangular and triangular sections.

Sharp-crested V-notch or triangular weirs are often used where accurate measurements of low flows are important. In the V-notch weir, a samll increase in flow during low flow will produce a relatively large increase in head and a good sensitivity of measurement. A V-notch weir may have a rectangular section above to accommodate infrequent high flows.

The two most common sharp-crested V-notch weirs are the 90° notch and the 120° notch, with metal blades ground to a sharp edge and built into a concrete cutoff wall. The 90° type gives greater sensitivity at low flows; the 120° type covers a wider range of flows. V-notch weirs are usually constructed to accommodate heads up to 2 feet; however, both in the United

States and elsewhere V-notch weirs capable of handling gage heights in excess of 2 feet are in use (See Appendix C).

Broad-crested triangular weirs with 2:1, 3:1, and 5:1 side slopes (with notches approximately 127°, 143°, and 157°, respectively) were developed and rated by the Soil Conservation Service for measuring flows up to about 1,000 c.f.s. The shape and thickness of the crest permits comparatively free passage of debris and minimizes the effect on the stage-discharge relationship of small irregularities of the crest and of trash temporarily lodged on the crest. A reasonably straight and practically level channel for 50 feet above the weir, with the notch 6 inches above the bottom of the approach channel, is essential for accuracy (See Appendix B).

Flumes

A flume is an artificial open channel built to contain flow within a designed cross-section and length. The types of flumes that have been used on small watersheds are described here.

HS, H, and HL flumes developed and rated by the Soil Conservation Service have converging vertical sidewalls cut back on a slope at the outlet to give them a trapezoidal projection. These have been used largely to measure intermittent runoff. Maximum depths of waterflow are 1 foot for the HS type, 4.5 feet for the H type, and 4 feet for the HL type. Maximum flows are 0.8, 84, and 117 c.f.s., respectively. These flumes are in use at many Agricultural Research Service installations and a number of other locations (See Appendix A).

The Venturi flume (Fig. 2) has a gradually contracting section leading to a constricted throat and an expanding section immediately downstream. The floor of the Venturi flume is the same grade as the stream channel, whereas that of the Parshall flume (described below) is depressed in the throat section. Stilling wells for measuring the head are at the entrance and at the throat; the difference in head at the two wells is related to discharge. Venturi flumes are rectangular, trapezoidal, triangular, or any other regular shape. They are widely used in measurement of irrigation water.

The Parshall flume, a modification of the Venturi flume, measures water in open conduits and is widely used, especially for measuring irrigation water. It consists essentially of a contracting inlet, a parallel-sided throat, and an expanding outlet, all of which have vertical sidewalls. It can measure flows under submerged conditions. Two water-level recorders are used when measuring submerged flow, one in the sidewall of the contracting inlet and the other slightly upstream from the lowest point of the flow in the throat. When measuring free flow, only the upper measuring point is used.

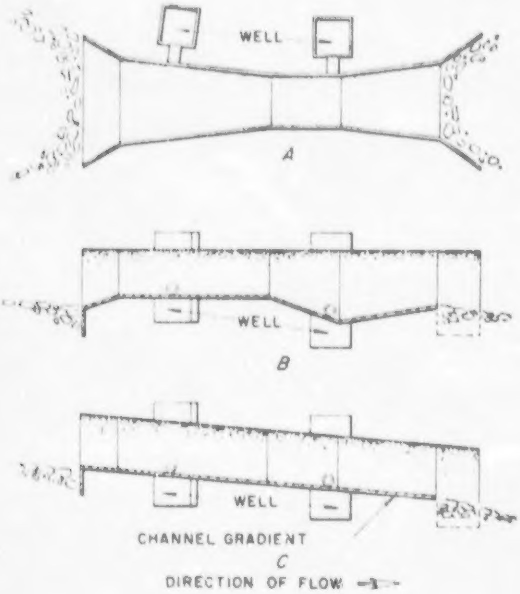


Fig. 2. Schematic diagram of Venturi flume, which requires measurment of stage at two points. Flume is same grade as stream channel. A, Plan view of Venturi flume; B, cross-section of Venturi flume.

The San Dimas flume (Fig. 3) was designed on the San Dimas Experimental Forest of the U.S. Forest Service to measure debris-laden flows in mountain streams. It is rectangular and has a sloping floor (3 percent gradient) that functions as a broad-crested weir except that the contraction is from the sides rather than the bottom; therefore, there is no barrier to cause sediment deposition. Depth measurements are made in the parallel-walled section at about the midpoint. Rapid flow keeps the flume scoured clean.

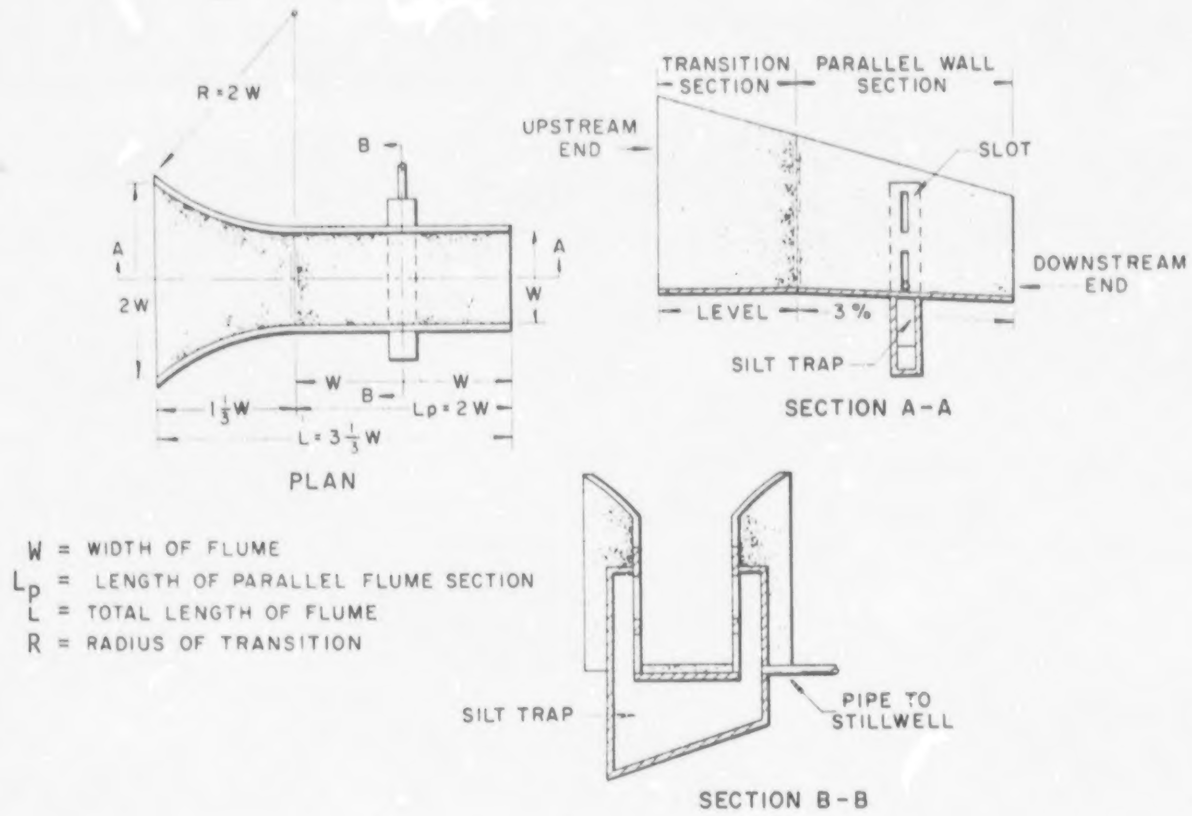

R = 2 W
B
A
A
2 W
W
W
B
W
$1\frac{1}{3}$W
Lp = 2 W
L = $3\frac{1}{3}$W
PLAN
TRANSITION SECTION
PARALLEL WALL SECTION
UPSTREAM END
SLOT
DOWNSTREAM END
LEVEL
3 %
SILT TRAP
SECTION A-A
W = WIDTH OF FLUME
L_p = LENGTH OF PARALLEL FLUME SECTION
L = TOTAL LENGTH OF FLUME
R = RADIUS OF TRANSITION
SILT TRAP
PIPE TO STILLWELL
SECTION B-B

Fig. 3. Generalized drawing of San Dimas flume. This design has been used for flumes with widths of 0.5, 1.0, 2.0, 3.0, 4.0, 6.0, and 10.0 feet.

The types of weirs and flumes that have been discussed are those most used in research. In some cases, structures have been built to incorporate features of more than one type; for example, a 90° V-notch recently built into a Trenton-type weir at the Pennsylvania State University. When a wide range in flow or sediment load is anticipated, it may be advantageous to install more than one device at the same site.

Summary

The type of gaging station to be used depends upon many factors: Maximum and minimum flows; accuracy needed in determining total discharge, high flows, and low flows; amount of sediment or debris that is expected, and whether it is suspended or bedload; channel gradient; channel cross-section; underlying material; accessibility of site; financial limitations; and length of study.

Maximum and minimum flows likely to be encountered must be estimated before construction. Such estimates can be made from observation of high and low flows and high watermarks and from information given by local residents, or they might be based on the area of the watershed and records from other gaging stations in the region. Maximum expected flood peaks can also be estimated from rainfall, soil, and cover data, using a method developed by the U.S. Soil Conservation Service. Assistance should be sought from the U.S. Geological Survey and U.S. Soil Conservation Service, if this approach is needed.

The maximum and minimum flow to be measured at any degree of precision depend upon the objectives of the study and the extremes that might occur. In some cases, a gage will be adequate if it will measure, with acceptable accuracy, 90 to 90 percent of the flow. These limits exclude extreme peaks and very low flows. However, the structure must be strong enough to withstand the highest flow expected.

Once maximum and minimum estimates are made, reference to rating tables for various structures or to formulas for computing flow will show the types and sizes of installations that can be used. Maximum and minimum discharges for several types of weirs and flumes are given in table 5.

Rating tables will also show the relationship between the increase in discharge and the corresponding rise in head at various stage heights. This association indicates the sensitivity of the gaging station at different levels of discharge.

Table 5. Maximum and minimum discharges for several types of weirs and flumes in cubic feet per second (approximate).

WEIRS

Type	Minimum	Maximum
Sharp-crested weirs:		
2 feet high, 90° V-notch	<0.001	14
2 feet high, 120° V-notch	<.001	24
2 feet high, 6 feet wide rectangular	[1].24	56
2.75 feet high, 8 feet wide Cipolletti	[1].30	123
4 feet high, 12 feet wide Cipolletti	[1].46	323
Broad-crested weirs:		
Triangular 2:1 side slopes	[2][2].017	[3]510
Triangular 3:1 side slopes	[2].025	[3]803
Triangular 5:1 side slopes	[2].037	[3]1,440
2 feet high Columbus deep notch	.026	62

FLUMES

HS type:		
0.4 foot high	[1]0.001	0.1
1.0 foot high	[1].002	.8
H type:		
1.0 foot high	[1].004	2
2.0 feet high	[1].007	11
4.5 feet high	[1].015	84
HL type:		
4.0 feet high	[1].03	117
San Dimas:		
1 foot wide	.1	6
3 feet wide	2	77
6 feet wide	10	318
10 feet wide	36	1,000
Trapezoidal:		
1-foot-wide throat, 4 feet high, 30° side slopes.	[1].15	350
Parshall:		
1 foot wide, 2.5 feet high	.4	16
2 feet wide, 2.5 feet high	.7	33
4 feet wide, 2.5 feet high	1.3	68
8 feet wide, 2.5 feet high.	4.6	140

[1] Flow at 0.05-foot head.

[2] Flow at 0.1-foot head.

[3] Flow at 6-foot head with cross-sectional area of 300 square feet in the channel of approach 10 feet upstream from center of crest.

Rating can be simplified by choosing a design for which a stage-discharge relationship has been determined in the laboratory. Before construction, the conditions under which the design was tested should be carefully studied. After construction, the laboratory rating should be checked at various gage heights by direct measurement with current meter, velocity head rod, or another instrument for determining velocity, or by volumetric measurements.

Where excessive amounts of suspended sediment, bedload, and floating debris are encountered, flumes are preferable. Weirs would be unsatisfactory because the basin would trap this material, which would alter the weir rating, and debris would clog the crest of the weir, giving grossly inaccurate measurements. Broad-crested weirs are often used on agricultural watersheds where grass and other debris would lodge on a sharp-crested weir and invalidate the rating curve.

The gradient of the stream channel may affect choice of design. If the gradient is too low, it may be impossible to install a weir that will meet the requirements of a standard rating (depth of water below crest equal to at least 2.5 times the maximum head to be measured). A control with less evaluation may have to be built, and the station will then have to be rated by current meter or other means.

The channel cross-section and streambanks may dictate design. Under some conditions, a cutoff wall high enough to satisfy rating requirements would have to be of considerable length to tie into solid material at the sides. The cost of such a wall might rule out this type of installation.

Underlying material must be considered. If permeability is a problem, either a watertight-box weir design, which can support an artificial head of water, or a flume will be necessary.

With weirs, sharp crests give greater accuracy than broad crests. Blades of sharp-crested weirs are constructed of angle iron or steelplate, ground to a sharp edge or to a flat edge one-sixteenth inch wide, and set into concrete cutoff walls or dams. Blades may be dented, bent, rusted, and clogged with debris. In many locations they must be screened to prevent clogging, and care should be exercised when working near them; some maintenance, such as annual painting, is required.

Flumes are often satisfactory where weirs are impracticable. They can handle debris laden flows better; even so, such flows may be difficult to measure. With flumes, velocity of approach is less of a problem than with weirs. There is less loss in head with flumes than with weirs; thus, they can be used in channels with low gradients; this is one of the main reasons why flumes are used in measurement of water for irrigation. And flumes, requiring no excavation for ponding may be easier and cheaper to install.

Details of constructing an H-flume, V-notch weir and sharp-crested weir are given in Appendices A, B and C. Methods for computing rainfall intensity from recording raingage charts and for computing runoff from a stage recorder chart are given in Appendix D.

LITERATURE

Much of this paper was taken directly from the following publications:

International Symposium of Forest. 1965. Edited by W. E. Sopper and H. W. Lull. Pergamon Press.

Field Manual for Research in Agricultural Hydrology. 1961. Agriculture Handbook No. 224. A.R.S.--U.S.D.A.

Stream-gaging Stations for Research on Small Watersheds. 1964. K. G. Reinhart and R. S. Pierce. Agriculture Handbook No. 268.

APPENDIX A

DESIGN SPECIFICATIONS FOR H-FLUMES

H FLUMES

H flumes measure runoff from watersheds where the maximum runoff ranges from 0.3 to 30 c.f.s. An H flume 0.5-foot deep would be used to gage a maximum flow of 0.3 c.f.s An H flume 3.0-foot deep can gage a maximum flow of 30 c.f.x. H-type flume dimensions and flow capacities are shown in figure 1.

Construction specificatons for the H-type rate-measuring flumes (riveted constuction) are as follows:

Service Requirements

To measure flows with the required degrees of accuracy, construct the flume in strict accordance with the drawing and the following proivisions of these specifications. It is especially important that the slanting opening be bounded by straight edges and have precisely the dimensions shown on the drawing (Fig. 1).

Drawings

Prepare detailed drawings, using proportional dimensions shown in Fig. 1.

Material

(1) General: Use only new materials of the best commercial quality and free from defects in the construction of the H flume.

(2) Sheet Metal: Use sheet metal of galvanized open-hearth iron of of copper-bearing steel.

(3) Structural Angles: Make all structural angles of high-grade structural steel, and galvanize the angles. The angles shall be straight, and the surface of the legs shall be planes.

(4) Rivets: Use only rivets of nonrusting ferrous alloy or of iron coated with nonrusting material.

Details of Construction

(1) General. Fabricate the flume by riveting and soldering. Make all joints and seams watertight and strong. Follow the best commercial practice in all details of construction.

(2) Cutting of Plates: Cut all plate edges straight and sharp. Do not warp the plates or otherwise distort by the cutting.

(3) Joints: Make the vertical sides of the flume from one sheet. The bottom plate shall not contain more than one joint and no portion of this joint shall lie within 12 inches of the outlet opening. Any necessary joint in the bottom plate shall be transverse to the longitudinal axis of the flume and shall be made so that the joint is substantially flush.

(4) Dimensions: Make all dimensions for which tolerances are not indicated on the drawings within one-fourth (1/4) inch of those given on the drawings.

(5) Outlet Opening: Form the slanting outlet opening with special care so that its dimensions are precisely as shown on the drawing. This means that the slopes indicated by the drawing must be rigidly adhered to. The edges of the outlet opening shall be straight and smooth.

(6) Fabrication: Clamp the plates rigidly in position and obtain the proper dimensions and slopes before the final connections are made. Make the side plates perpendicular to the bottom of the flume. All cross-sections of the flume shall be symmetrical about the longitudinal axis. All plates shall be flat and shall display no appreciable warp, dent, or other form of distortion.

(7) Riveting: Carry out all riveting in such a way that no projections occur on the inside of the flume. Fill all depressions in the surface of the plates forming the inside of the flume with solder, and dress the solder smooth and flush with the surfaces of the plates. All rivets shall be solid and watertight.

Workmanship

A skilled mechanic shall carry out all operations affecting the dimensions of the outlet opening and the straightness of its edges and he shall follow good machine shop practice. The best sheet metal shop practices shall be followed in all other operations. The completed flume shall display no deep tool marks, dents, or other blemishes.

Shipment

Crate the flume or otherwise protect it from damage during shipment. The contractor shall be responsible for any damage arising from lack of adequate protection.

Inspection

Upon delivery, inspect the flume to confirm its compliance with the plans and specifications. Do not make final acceptance of the flume until this inspection has demonstrated that all dimensions, materials, and workmanship are satisfactory.

H flumes 4.5-foot deep can be constructed in the field, if the proportional dimensions given in figure 1 are used. The flow capacity of this flume is 84 c.f.x. Reinforced concrete floor resting on two reinforced concrete footings--one across the upper face of the flume and the other about 1 foot in from the downstream edge--provides a substantial base for the flume walls. These walls may be either concrete or wood treated with preservative. In either case, angle iron forms the sloping edge of the flume. Sometimes the wood walls are lined with sheet metal. The wood should be 2-inch shiplap or tongue-and-grooved siding with watertight joints.

Calibration of the H-type flumes is given in table 1.

Installation

Installation of these flumes should, whenever possible, be made with approach boxes depressed below the natural ground surface as shown in figure 2. Where the watershed slope is small and the flow dispersed, it may be necessary to use gutters to collect the runoff at the bottom of the slope and channel it into the approach box. These gutters and the approach box are sometimes covered to prevent complication of runoff record by rain falling thereon.

Metal flumes are bolted to the concrete approach with gaskets to make a watertight joint. The concrete cutoff will extend below the concrete approach at the upstream face of the flume to provide substantial support and to prevent seepage below the flume. A drain tile provides release of water from below the flume. Leveling bolts on the downstream supporting wall are used to fasten and level the flume.

The flume floor must be level. If silting is a problem, a 1-on-8 sloping false floor can be set in to concentrate low flows and thereby reduce silting. The difference in calibration of a flume with a flat floor and that with a sloping false floor is less than 1 percent.

A stilling well for water stage recorder floats is usually made of sheet metal attached to the flume wall. Openings to the flume are provided to supply ready exchange of water between the flume and the stilling well. Support and shelter for the water stage recorders are fastened to the flume wall. Instructions for setting the recorder are given below.

Where freezing temperatures are expected, the well should be heated automatically or drained automatically after each runoff period.

Water Level Recorders

Instructions for setting water-level recorders are as follows:

(1) Form temporary watertight pool around intakes outside of stilling wall.

(2) Raise water level in stilling well until it is 1 or 2 inches above lowest intake.

(3) Place water level recorder on floor of shelter or on shelf; install float, counterweight, and graduated float tape in position; install tape index pointer (I.P.); insert clock; place chart paper on clock; fill pen with ink and place it in position to record.

(4) Observe the record for about 5 minutes to see if the setup is watertight. If the water level drops during this period, find the leak and repair it.

(5) With surveyor's level take backsight (B.S.) on crest of flume or notch of weir to get the elevation of the height of instrument (H.I.). All rod readings are to 0.001 foot.

(6) Attach plumb bob to steel tape graduated in 0.01 foot. Set point of plumb bob at elevation of H.I. and read tape at horizontal index

line (L) marked on shelter or any other convenient object over the pool. (Estimate tape reading to 0.001 foot.)

(7) Lower plumb bob to water surface of pool and read tape at index line. Repeat this step for a check.

(8) Read tape index pointer on float tape immediately after operation (7).

(9) Subtract difference of tape readings at (L) of steps (6) and (7) from height of instrument to get elevation of water surface.

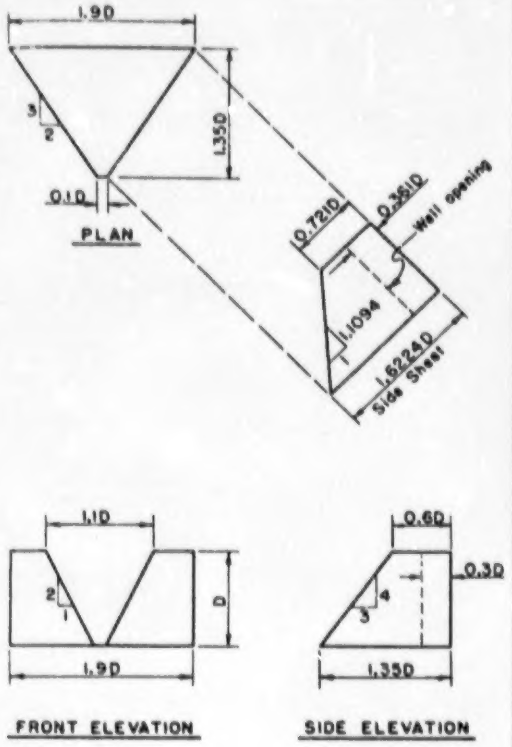
(10) Check height of instrument by rod reading on flume crest.

(11) The difference between readings (8) and (9) is the amount the float must be lowered (if (8) is less than (9)), or raised (if (8) is greater than (9)) on the float tape. Minor adjustments up to 0.05 foot can be made by adjusting index pointer.

(12) Set pen on chart to read water surface elevation obtained in step (9).

(13) Check operations 5 to 12 with water at a different level.

Figure 1. H flume dimensions and capacities


1.9D
1.35D
3
2
0.1D
PLAN
0.721D
0.351D
Wall opening
1.1094
1.6224D
Side Sheet
1.1D
D
2
1
1.9D
FRONT ELEVATION
0.6D
0.3D
4
3
1.35D
SIDE ELEVATION

PROPORTIONS OF THE TYPE H FLUME

APPROXIMATE CAPACITIES	
DEPTH-D Feet	CAPACITY C.f.s.
0.5	0.3+
0.75	1-
1.0	2
1.5	5+
2.0	11
2.5	19
3.0	30+

Note: For flumes less than 1 foot deep, the length of flume is made greater than 1.35D so that the float may be attached.

Figure 2. Plans for straight headwall and for drop box installations of H flumes

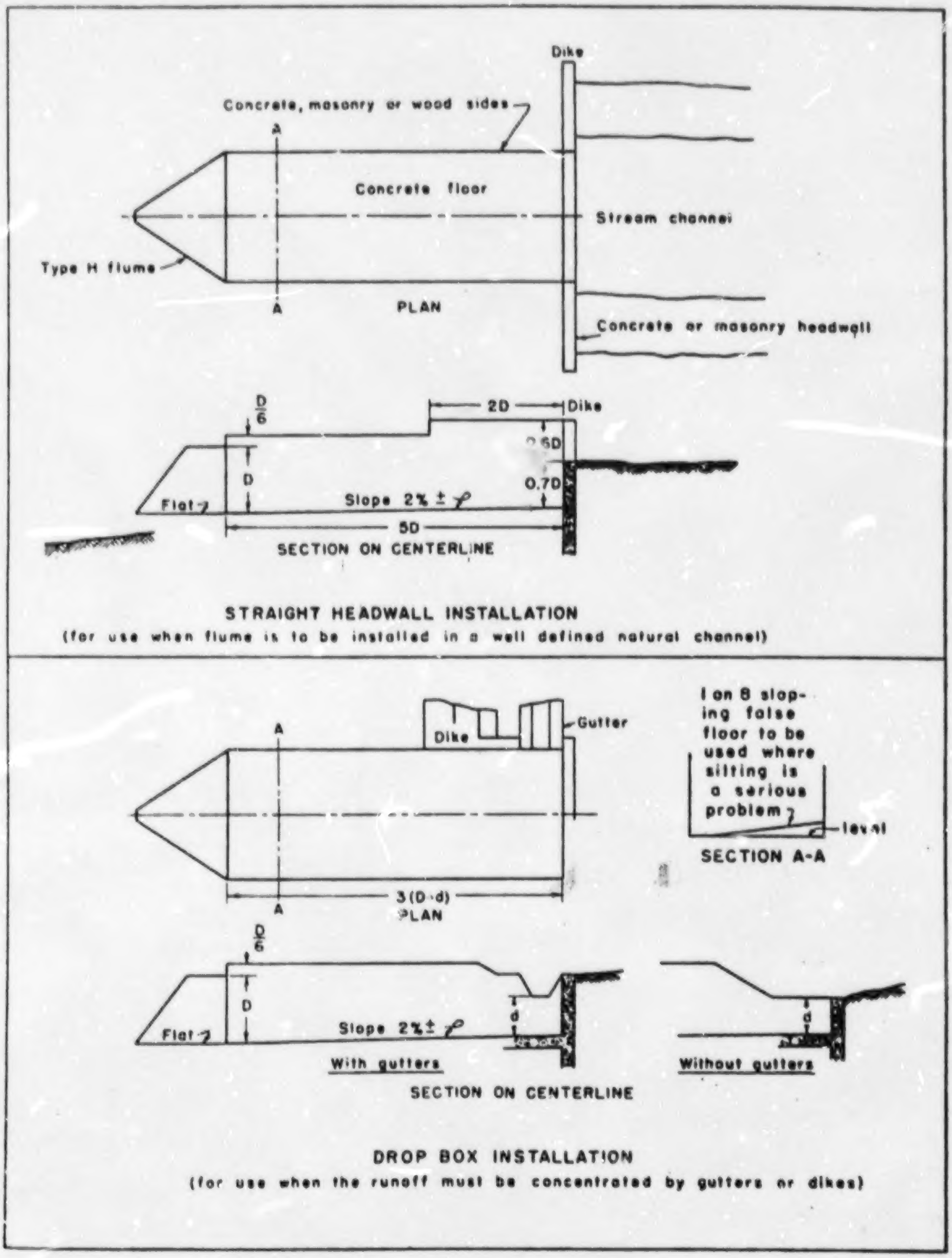

Dike
Concrete, masonry or wood sides
A
Concrete floor
Stream channel
Type H flume
A
PLAN
Concrete or masonry headwall
$\frac{D}{6}$
2D
Dike
0.6D
D
0.7D
Flat
Slope 2% ±
5D
SECTION ON CENTERLINE
STRAIGHT HEADWALL INSTALLATION
(for use when flume is to be installed in a well defined natural channel)
Dike
Gutter
A
1 on 8 sloping false floor to be used where silting is a serious problem
level
SECTION A-A
3(D-d)
A
PLAN
$\frac{D}{6}$
D
d
Flat
Slope 2% ±
With gutters
d
Without gutters
SECTION ON CENTERLINE
DROP BOX INSTALLATION
(for use when the runoff must be concentrated by gutters or dikes)

Table 1. Rating tables for H flume[1]

(Discharge in cubic feet per second)

FLUME 0.5 FOOT DEEP

Head (feet)	0.00	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09
0	0	(2)	0.0004	0.0009	0.0016	0.0024	0.0035	0.0047	0.0063	0.0080
0.1	.0101	.0122	.0146	.0173	.0202	.0233	0.267	.0304	.0343	.0385
0.2	.0431	.0479	.0530	.0585	.0643	.0704	.0767	.0834	.0905	.0979
0.3	.1057	.1139	.1224	.1314	.1407	.1505	.1607	.1713	.1823	.1938
0.4	.205	.217	.230	.244	.257	.271	.285	.300	.315	.331

FLUME 0.75 FOOT DEEP

Head (feet)	0.00	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09
0	0	(2)	0.0006	0.0013	0.0022	0.0032	0.0046	0.0061	0.0080	0.0101
0.1	.0126	.0151	.0179	.0210	.0242	.0278	.0317	.0358	.0403	.0451
0.2	.0501	.0555	.0612	.0672	.0735	.0802	.0872	.0946	.1023	.1104
0.3	.119	.128	.137	.146	.156	.167	.177	.188	.199	.211
0.4	.224	.237	.250	.263	.277	.291	.306	.321	.337	.353
0.5	.370	.388	.406	.424	.443	.462	.482	.502	.523	.544
0.6	.566	.588	.611	.635	.659	.683	.708	.734	.760	.786
0.7	.813	.841	.869	.898	.927	.957	--------	--------	--------	--------

FLUME 1.0 FOOT DEEP

Head (feet)	0.00	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09
0	0	(2)	0.0007	0.0017	0.0027	0.0040	0.0056	0.0075	0.0097	0.0122
0.1	.0150	.0179	.0211	.0246	.0284	.0324	.0367	.0413	.0462	.0515
0.2	.0571	.0630	.0692	.0758	.0827	.0900	.0976	.1055	.1138	.1226
0.3	.132	.141	.151	.161	.172	.183	.194	.206	.218	.231
0.4	.244	.257	.271	.285	.300	.315	.331	.347	.364	.381
0.5	.398	.416	.434	.453	.472	.492	.512	.533	.554	.576
0.6	.598	.621	.644	.668	.692	.717	.743	.769	.795	.823
0.7	.851	.880	.909	.939	.969	1.000	1.031	1.063	1.096	1.129
0.8	1.16	1.20	1.23	1.27	1.30	1.34	1.38	1.41	1.45	1.49
0.9	1.53	1.57	1.61	1.66	1.70	1.74	1.78	1.83	1.87	1.92

FLUME 1.5 FEET DEEP

Head (feet)	0.00	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09
0	0	(2)	0.0011	0.0023	0.0039	0.0057	0.0078	0.0103	0.0131	0.0164
0.1	.0200	0.0237	.0276	.0319	.0365	.0414	.0467	.0523	.0582	.0645
0.2	.0711	.0780	.0854	.0931	.1011	.1095	.1183	.1275	.1371	.1470
0.3	.157	.168	.179	.191	.203	.215	.228	.241	.255	.269
0.4	.283	.298	.314	.330	.346	.363	.380	.398	.416	.435
0.5	.454	.473	.493	.514	.535	.557	.579	.601	.624	.648
0.6	.672	.697	.722	.747	.773	.800	.827	.855	.883	.912
0.7	.942	.972	1.002	1.033	1.065	1.097	1.130	1.163	1.197	1.231
0.8	1.27	1.30	1.34	1.38	1.41	1.45	1.49	1.53	1.57	1.61
0.9	1.65	1.69	1.73	1.78	1.82	1.86	1.91	1.95	2.00	2.05
1.0	2.09	2.14	2.19	2.24	2.30	2.35	2.40	2.45	2.50	2.56
1.1	2.61	2.67	2.73	2.78	2.84	2.90	2.96	3.02	3.08	3.14
1.2	3.20	3.27	3.33	3.39	3.46	3.52	3.59	3.66	3.73	3.80
1.3	3.87	3.94	4.01	4.08	4.15	4.22	4.30	4.37	4.45	4.52
1.4	4.60	4.68	4.76	4.84	4.92	5.00	5.08	5.16	5.24	5.33

See footnotes at end of table

Table 1. Rating tables for H flume--Continued

FLUME 2.0 FEET DEEP

0	0	(¹)	0.0014	0.0031	0.0050	0.0073	0.0100	0.0130	0.0166	0.0205
0.1	.0248	0.0293	.0341	.0392	.0447	.0505	.0567	.0632	.701	.0774
0.2	.0850	.0930	.1015	.1103	.1195	.1290	.1390	.1494	.1602	.1714
0.3	.183	.195	.207	.220	.234	.248	.262	.276	.291	.307
0.4	.323	.339	.356	.374	.392	.410	.429	.448	.468	4.88
0.5	.509	.530	.552	.574	.597	.620	.644	.668	.693	.719
0.6	.745	.771	.798	.826	.854	.882	.911	.941	.971	1.002
0.7	1.03	1.07	1.10	1.13	1.16	1.20	1.23	1.27	1.30	1.34
0.8	1.38	1.42	1.46	1.49	1.53	1.57	1.62	1.66	1.70	1.74
0.9	1.78	1.83	1.87	1.92	1.96	2.01	2.06	2.10	2.15	2.20
1.0	2.25	2.30	2.35	2.40	2.45	2.51	2.56	2.62	2.67	2.73
1.1	2.78	2.84	2.90	2.96	3.02	3.08	3.14	3.20	3.26	2.32
1.2	3.38	3.45	3.51	3.58	3.65	3.71	3.78	3.85	3.92	3.99
1.3	4.06	4.13	4.20	4.28	4.35	4.43	4.50	4.58	4.66	4.74
1.4	4.82	4.90	4.98	5.06	5.14	5.23	5.31	5.40	5.48	5.57
1.5	5.65	5.74	5.83	5.92	6.01	6.11	6.20	6.29	6.38	6.48
1.6	6.58	6.67	6.77	6.87	6.97	7.07	7.17	7.27	7.37	7.47
1.7	7.58	7.68	7.79	7.90	8.00	8.11	8.22	8.33	8.44	8.56
1.8	8.67	8.78	8.90	9.01	9.12	9.24	9.36	9.48	9.60	9.72
1.9	9.85	9.97	10.09	10.21	10.34	10.47	10.60	10.72	10.85	10.98

FLUME 2.5 FEET DEEP

Head (feet)	0.00	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09
0	0	(¹)	0.0018	0.0038	0.0061	0.0089	0.0121	0.0158	0.0200	0.0247
0.1	.0298	0.0350	.0406	.0465	.0528	.0595	.0666	.0741	.0820	.0903
0.2	.0990	.1081	.1176	.1275	.1379	.1486	.1597	.1713	.1834	.1960
0.3	.209	.222	.236	.250	.265	.280	.296	.312	.328	.345
0.4	.363	.381	.399	.418	.437	.457	.478	.499	.520	.542
0.5	.564	.587	.611	.635	.659	.684	.710	.736	.763	.790
0.6	.818	.846	.875	.904	.934	.965	.996	1.027	1.059	1.092
0.7	1.13	1.16	1.19	1.23	1.27	1.30	1.34	1.38	1.41	1.45
0.8	1.49	1.53	1.57	1.61	1.65	1.70	1.74	1.78	1.83	1.87
0.9	1.92	1.96	2.01	2.06	2.11	2.16	2.21	2.26	2.31	2.36
1.0	2.41	2.46	2.51	2.57	2.62	2.68	2.74	2.79	2.85	2.91
1.1	2.97	3.03	3.09	3.15	3.21	3.27	3.33	3.40	3.46	3.53
1.2	3.59	3.66	3.73	3.80	3.86	3.93	4.00	4.07	4.15	4.22
1.3	4.29	4.37	4.44	4.52	4.59	4.67	4.75	4.82	4.90	4.98
1.4	5.06	5.15	5.23	5.31	5.39	5.48	5.56	5.65	5.74	5.82
1.5	5.91	6.00	6.09	6.18	6.27	6.37	6.46	6.55	6.65	6.75
1.6	6.84	6.94	7.04	7.14	7.24	7.34	7.45	7.55	7.66	7.76
1.7	7.86	7.97	8.08	8.19	8.30	8.41	8.53	8.64	8.75	8.87
1.8	8.98	9.10	9.22	9.34	9.45	9.57	9.70	9.82	9.94	10.06
1.9	10.2	10.3	10.4	10.6	10.7	10.8	11.0	11.1	11.2	11.4
2.0	11.5	11.6	11.8	11.9	12.0	12.2	12.3	12.5	12.6	12.7
2.1	12.9	13.0	13.2	13.3	13.5	13.6	13.8	13.9	14.1	14.2
2.2	14.4	14.5	14.7	14.8	15.0	15.1	15.3	15.5	15.6	15.8
2.3	16.0	16.1	16.3	16.4	16.6	16.8	17.0	17.1	17.3	17.5
2.4	17.6	17.8	18.0	18.2	18.3	18.5	18.7	18.9	19.1	19.2

See footnotes at end of table

Table 1. Rating tables for H flume--Continued

FLUME 3.0 FEET DEEP

Head (feet)	0.00	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09
0.	0	(*)	0.0021	0.0045	0.0073	0.0105	0.0143	0.0186	0.0234	0.0288
0.1	.0347	0.0407	.0471	.0538	.0610	.0686	.0766	.0851	.0939	.1032
0.2	.113	.123	.134	.145	.156	.168	.180	.193	.207	.220
0.3	.234	.249	.264	.280	.296	.312	.329	.347	.365	.383
0.4	.402	.421	.441	.462	.483	.504	.526	.549	.572	.596
0.5	.620	.644	.669	.695	.721	.748	.775	.803	.832	.861
0.6	.890	.920	.951	.982	1.014	1.047	1.080	1.113	1.147	1.182
0.7	1.22	1.25	1.29	1.33	1.36	1.40	1.44	1.48	1.52	1.56
0.8	1.60	1.65	1.69	1.73	1.78	1.82	1.86	1.91	1.96	2.00
0.9	2.05	2.10	2.15	2.20	2.25	2.30	2.35	2.41	2.46	2.51
1.0	2.57	2.62	2.68	2.73	2.79	2.85	2.91	2.97	3.03	3.09
1.1	3.15	3.21	3.27	3.34	3.40	3.46	3.53	3.60	3.66	3.73
1.2	3.80	3.87	3.94	4.01	4.08	4.15	4.23	4.30	4.37	4.45
1.3	4.53	4.60	4.68	4.76	4.84	4.92	5.00	5.08	5.16	5.24
1.4	5.33	5.41	5.50	5.58	5.67	5.76	5.84	5.93	6.02	6.11
1.5	6.20	6.30	6.39	6.48	6.58	6.67	6.77	6.87	6.96	7.06
1.6	7.16	7.26	7.36	7.47	7.57	7.67	7.78	7.88	7.99	8.10
1.7	8.20	8.31	8.42	8.53	8.64	8.75	8.87	8.98	9.10	9.21
1.8	9.33	9.45	9.56	9.68	9.80	9.92	10.05	10.17	10.29	10.41
1.9	10.5	10.7	10.8	10.9	11.0	11.2	11.3	11.4	11.6	11.7
2.0	11.9	12.0	12.1	12.3	12.4	12.6	12.7	12.8	13.0	13.1
2.1	13.3	13.4	13.6	13.7	13.9	14.0	14.2	14.3	14.5	14.6
2.2	14.8	14.9	15.1	15.3	15.4	15.6	15.7	15.9	16.1	16.2
2.3	16.4	16.6	16.7	16.9	17.1	17.2	17.4	17.6	17.8	17.9
2.4	18.1	18.3	18.5	18.7	18.8	19.0	19.2	19.4	19.6	19.8
2.5	19.9	20.1	20.3	20.5	20.7	20.9	21.1	21.3	21.5	21.7
2.6	21.9	22.1	22.3	22.5	22.7	22.9	23.1	23.3	23.5	23.7
2.7	23.9	24.1	24.3	24.5	24.7	24.9	25.2	25.4	25.6	25.8
2.8	26.0	26.2	26.5	26.7	26.9	27.1	27.4	27.6	27.8	28.0
2.9	28.3	28.5	28.7	28.9	29.2	29.4	29.7	29.9	30.1	30.4

See footnotes at end of table

Table 1. Rating tables for H flume--Continued

FLUME 4.5 FEET DEEP

Head (feet)	0.00	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09
0	0	([2])	0.0031	0.0066	0.0106	0.0154	0.0208	0.0269	0.0337	0.0413
0.1	.0496	0.0578	.0666	.0758	.0855	.0959	.1067	.1180	.1298	.1420
0.2	.155	.168	.182	.196	.211	.226	.242	.259	.276	.293
0.3	.311	.330	.349	.368	.388	.409	.430	.452	.474	.497
0.4	.520	.544	.569	.594	.620	.646	.673	.700	.728	.756
0.5	.785	.815	.845	.876	.907	.939	.972	1.005	1.039	1.073
0.6	1.11	1.14	1.18	1.122	1.25	1.29	1.33	1.38	1.41	1.45
0.7	1.49	1.53	1.58	1.62	1.66	1.71	1.75	1.80	1.84	1.89
0.8	1.94	1.99	2.04	2.09	2.14	2.19	2.24	2.29	2.35	2.40
0.9	2.45	2.51	2.56	2.62	2.68	2.74	2.79	2.85	2.91	2.96
1.0	3.04	3.10	3.16	3.22	3.29	3.35	3.42	3.49	3.55	3.62
1.1	3.69	3.76	3.83	3.90	3.97	4.04	4.12	4.19	4.27	4.34
1.2	4.42	4.50	4.58	4.65	4.73	4.81	4.89	4.98	5.06	5.14
1.3	5.22	5.31	5.39	5.48	5.57	5.66	5.74	5.83	5.92	6.02
1.4	6.11	6.20	6.29	6.39	6.48	6.58	6.68	6.77	6.87	6.97
1.5	7.07	7.17	7.27	7.37	7.48	7.59	7.69	7.80	7.90	8.01
1.6	8.12	8.23	8.34	8.45	8.56	8.68	8.79	8.90	9.02	9.14
1.7	9.25	9.37	9.49	9.61	9.73	9.85	9.98	10.10	10.22	10.35
1.8	10.5	10.6	10.7	10.8	11.0	11.1	11.2	11.4	11.5	11.6
1.9	11.8	11.9	12.0	12.2	12.3	12.5	12.6	12.8	12.9	13.0
2.0	13.2	13.3	13.5	13.6	13.7	13.9	14.1	14.2	14.4	14.5
2.1	14.7	14.8	15.0	15.2	15.3	15.5	15.6	15.8	15.9	16.1
2.2	16.3	16.4	16.6	16.8	16.9	17.1	17.3	17.4	17.6	17.8
2.3	18.0	18.1	18.3	18.5	18.7	18.8	19.0	19.2	19.4	19.6
2.4	19.7	19.9	20.1	20.3	20.5	20.7	20.9	21.0	21.2	21.4
2.5	21.6	21.8	22.0	22.2	22.4	22.6	22.8	23.0	23.2	23.4
2.6	23.6	23.8	24.0	24.2	24.4	24.6	24.9	25.1	25.3	25.5
2.7	25.7	25.9	26.1	26.4	26.6	26.8	27.0	27.2	27.4	27.7
2.8	27.9	28.1	28.4	28.6	28.8	29.0	29.3	29.5	29.7	30.0
2.9	30.2	30.4	30.7	30.9	31.2	31.4	31.7	31.9	32.2	32.4
3.0	32.7	32.9	33.2	33.4	33.7	33.9	34.2	34.4	34.7	35.0
3.1	35.2	35.5	35.8	36.0	36.3	36.6	36.8	37.1	37.4	37.7
3.2	37.9	38.2	38.5	38.8	39.0	39.3	39.6	39.9	40.2	40.5
3.3	40.8	41.2	41.3	41.6	41.9	42.2	42.5	42.8	43.1	43.4
3.4	43.7	44.0	44.3	44.6	44.9	45.2	45.5	45.8	46.1	46.4
3.5	46.8	47.1	47.4	47.7	48.0	48.3	48.6	49.0	49.3	49.6
3.6	49.9	50.3	50.6	50.9	51.2	51.6	51.9	52.2	52.6	52.9
3.7	53.2	53.6	53.9	54.3	54.6	54.9	55.3	55.6	56.0	56.2
3.8	56.7	57.0	57.4	57.7	58.1	58.4	58.8	59.2	59.5	59.9
3.9	60.2	60.6	61.0	61.3	61.7	62.1	62.4	62.8	63.2	63.6
4.0	63.9	64.3	64.7	65.1	65.4	65.8	66.2	66.6	67.0	67.4
4.1	67.8	68.2	68.5	68.9	69.3	69.7	70.1	70.5	70.9	71.3
4.2	71.7	72.1	72.5	72.9	73.3	73.8	74.2	74.6	75.0	75.4
4.3	75.8	76.2	76.6	77.1	77.5	77.9	78.3	78.8	79.2	79.6
4.4	80.0	80.5	80.9	81.3	81.8	82.2	82.6	83.1	83.5	84.0

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[1] Rating derived from tests made by the Soil Conservation Service at the Hydraulic Laboratory of the National Bureau of Standards using 1-on-8 sloping false floor.

[2] Trace.

APPENDIX B

DESIGN SPECIFICATIONS FOR TRIANGULAR WEIRS

TRIANGULAR WEIRS

Triangular weirs with 2-to-1, 3-to-1, 5-to-1, and 10-to-1 crests have been developed to measure flows more than 1,000 c.f.s. A reasonably straight and practically level channel for 50 feet above the weir, with the notch 6 inches above the bottom of the approach channel, is essential for accuracy.

Cross-sectional dimensions are given in figure 3. A substantial apron of concrete for about 12 feet downstream from the weir, 2 feet below the notch, 20 feet across the channel, and with a 3-foot (plus) end cutoff wall is needed to protect the weir from being undermined. The middle 10-foot width of this apron is level and the two 5-foot sides are sloped slightly more than the weir crest.

The Rating Table

Calibration of these weirs, as given in table 2, is affected by velocity of approach. The cross-sectional area of the approach channel 10-feet upstream from the weir, at the point of recording gage heights, is a measure of the approach velocity. The rating table supplies discharge figures at each foot of head from 1 to 6 feet for a number of different areas of cross-section. For example, the discharge for a 3-to-1 weir at 2-foot head and a section area of 40 sq. ft. is 48.7 c.f.s. For a 62-sq. ft. section area, the discharge is 47.5 c.f.s.

The stage-discharge relation is developed for these weirs by plotting a graph of the discharge value from the proper rating table against head at each foot of stage. Rating values below 0.7 foot are obtained from table 3. On the graph paper, the rating curve is extended upwards from the 0.7-foot value through the 1-, 2-, 3-, 4-, 5-, and 6-foot plotted points. A rating table for each 0.01-foot head is then derived from this curve. Whenever practical, make current-meter measurments to check this calibration. Any large changes occurring in the approach cross-section, either cutting or filling, may require a revision of the calibration.

Pondage Corrections

Pondage corrections will need to be applied to many of the small watersheds to obtain natural rates of runoff from the area. A contour map of the pond area (figure 4) is used to compute pondage rates corresponding to rates of change in stage.

(1) Determine the area within each contour up to the estimated maximum high water by planimeter. The results of this are shown in volumes 1 to 4 of figure 5.

(2) Divide the area in square feet by 60 to obtain the q_p values in cubic feet per second for each contour. These values, shown in column 5, are the rate of ponding in cubic feet per second for a rate of change in stage of 1 foot per minute. (The rate of ponding could have been computed for any other rate of change in stage, such as 0.1, 0.01 foot per minute; feet per hour; or feet per second.)

(3) Plot the q_p values obtained in step 2 against the gage datum elevation and draw a smooth curve through the points. Additional values are picked from this curve at each 0.1 foot of stage and tabulated in column 5.

(4) Tabulate the values of q_p from column 5 of figure 5 to three significant figures on the right half of figure 6. Values for each 0.01 foot of stage are then obtained by interpolation. No values are tabulated for stages below 1.10 G.D.E. which is the elevation of the lowest intake.

Pondage Volume Curve

If the total runoff for each day, from midnight to midnight is to be calculated, it is necessary to take into account the difference in amounts stored at the beginning and end of the day. Use the areas of the pond obtained from figure 4 to compute the volume of the pond for various stages. Convert these volumes from cubic feet to inches by dividing by volume per 1-inch depth over the watershed area (3,630 X acres in drainage area). Plot watershed inches against gage datum elevation and draw a smooth curve through the points. The computations and curves are shown in figure 7.

Figure 3. Shape of a standard cross section of a triangular weir with a 16-inch crest

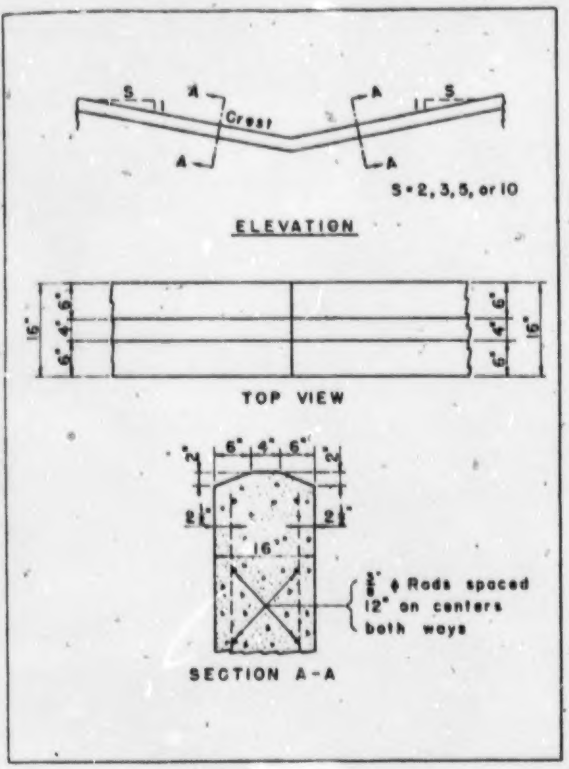

S
A
Crest
A
A
S
A
S = 2, 3, 5, or 10
ELEVATION
16"
6"
4"
6"
6"
4"
6"
16"
TOP VIEW
2"
6"
4"
6"
2"
2½"
2½"
16"
3/8" ϕ Rods spaced 12" on centers both ways
SECTION A-A

Figure 4. Contour map of a pond area

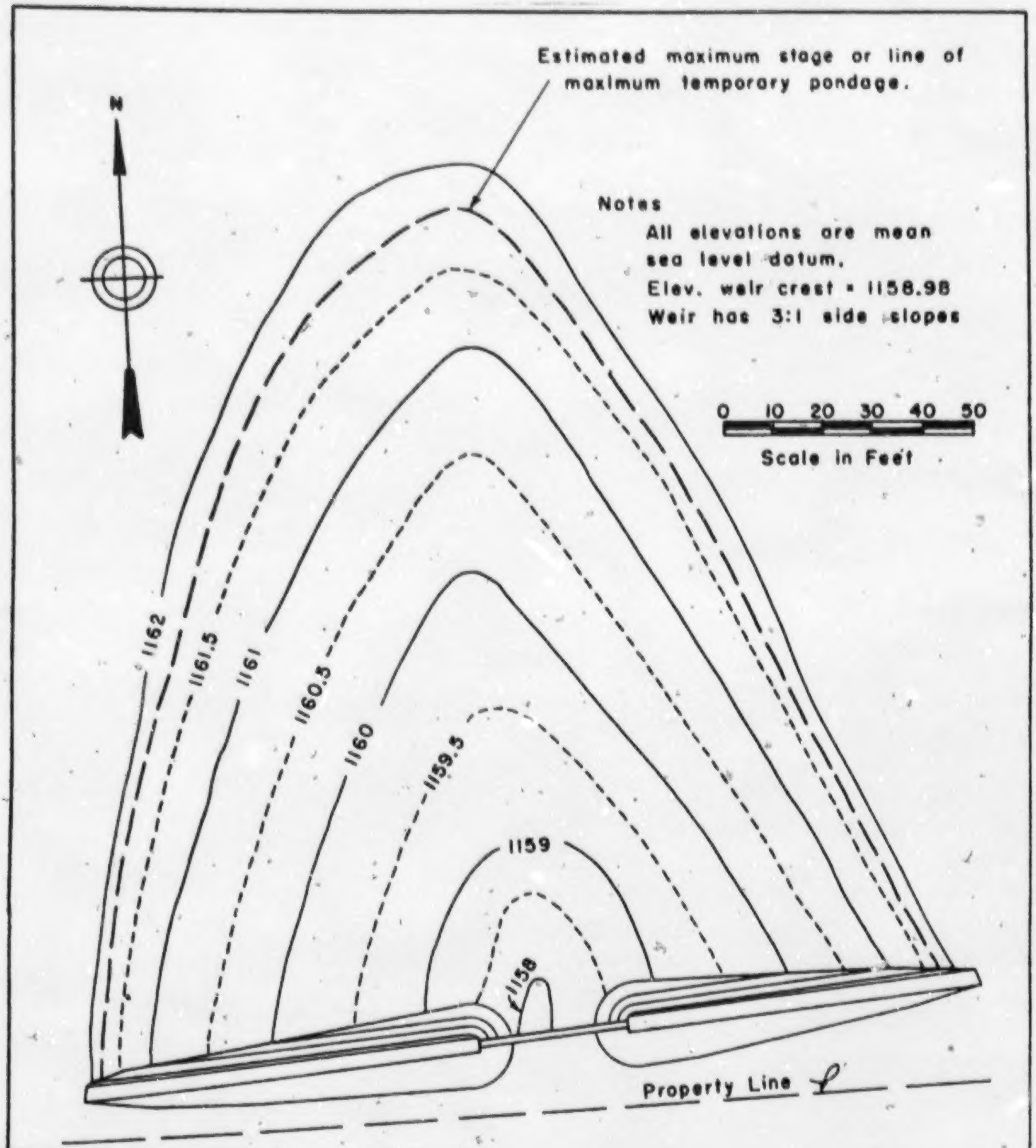
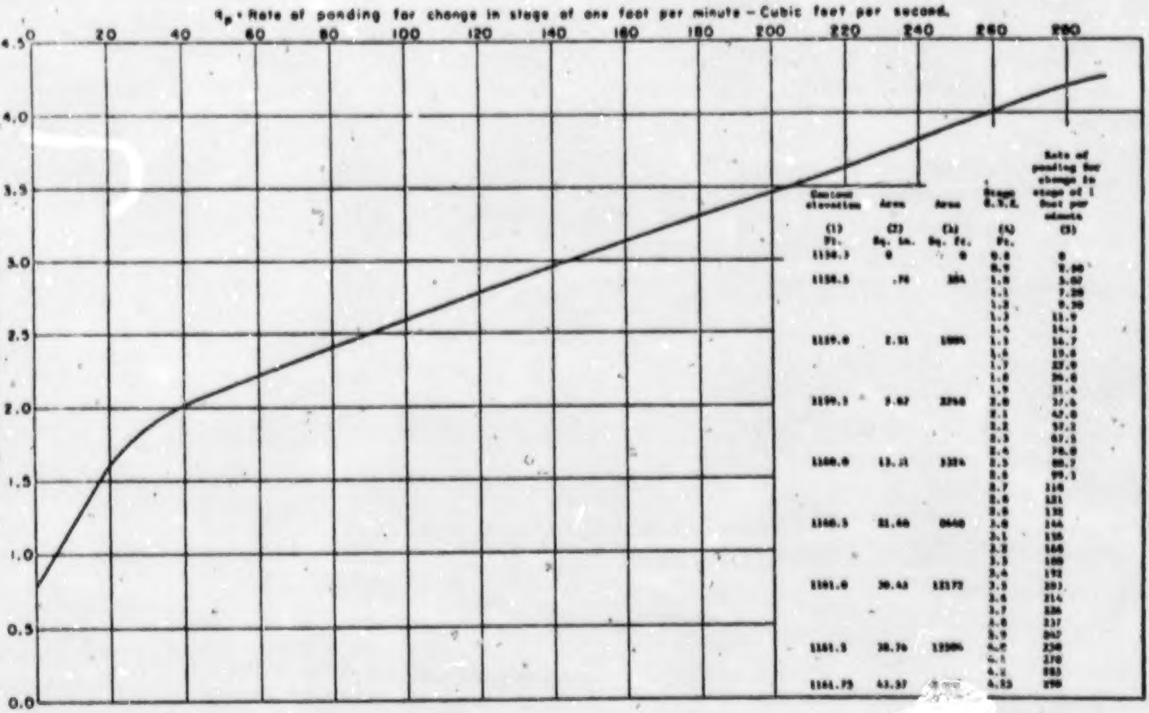
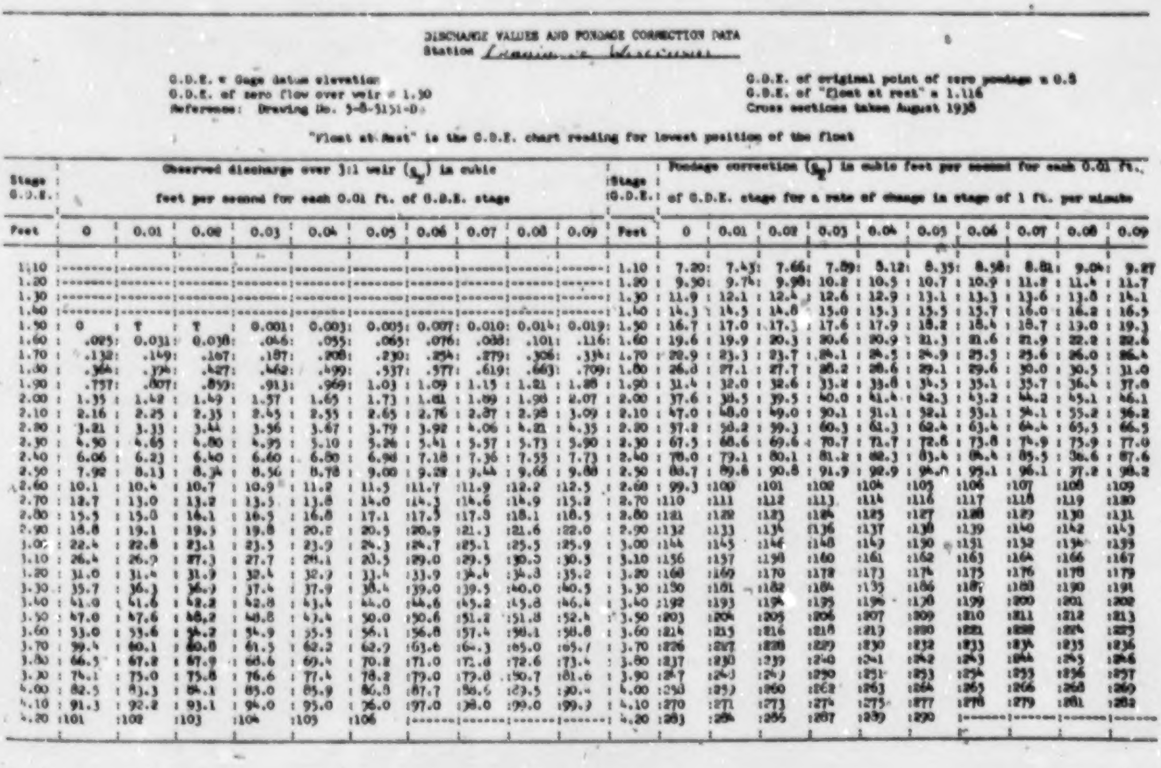

Estimated maximum stage or line of maximum temporary pondage.
N
Notes
All elevations are mean sea level datum.
Elev. weir crest = 1158.98
Weir has 3:1 side slopes
0
10
20
30
40
50
Scale in Feet
1162
1161.5
1161
1160.5
1160
1159.5
1159
1158
Property Line ℓ
Centerline of Town Road ℓ

Figure 5. Pondage rates for each contour of pond area and pondage correction curve



Contour elevation (1) Ft.	Area (2) Sq. in.	Area (3) Sq. ft.	Stage G.D.E. (4) Ft.	Rate of ponding for change in stage of 1 foot per minute (5)
1158.3	0	0	0.8	0
			0.9	2.80
1158.5	.76	304	1.0	5.02
			1.1	7.20
			1.2	9.30
			1.3	11.9
			1.4	14.3
1159.0	2.51	1004	1.5	16.7
			1.6	19.6
			1.7	22.9
			1.8	26.8
			1.9	31.4
1159.5	5.65	2260	2.0	37.6
			2.1	47.0
			2.2	57.2
			2.3	67.5
			2.4	78.0
1160.0	13.21	5284	2.5	88.7
			2.6	99.1
			2.7	110
			2.8	121
			2.9	132
1160.5	21.60	8640	3.0	144
			3.1	156
			3.2	168
			3.3	180
			3.4	192
1161.0	30.43	12172	3.5	203
			3.6	214
			3.7	226
			3.8	237
			3.9	242
1161.5	38.76	15504	4.0	250
			4.1	270
			4.2	283
1161.75	43.37	[illegible]	4.25	290

Figure 6. Discharge values for 3-to-1 weir and pondage correction data for station W-II, Fennimore, Wisconsin



DISCHARGE VALUES AND PONDAGE CORRECTION DATA
Station *Fennimore, Wisconsin*

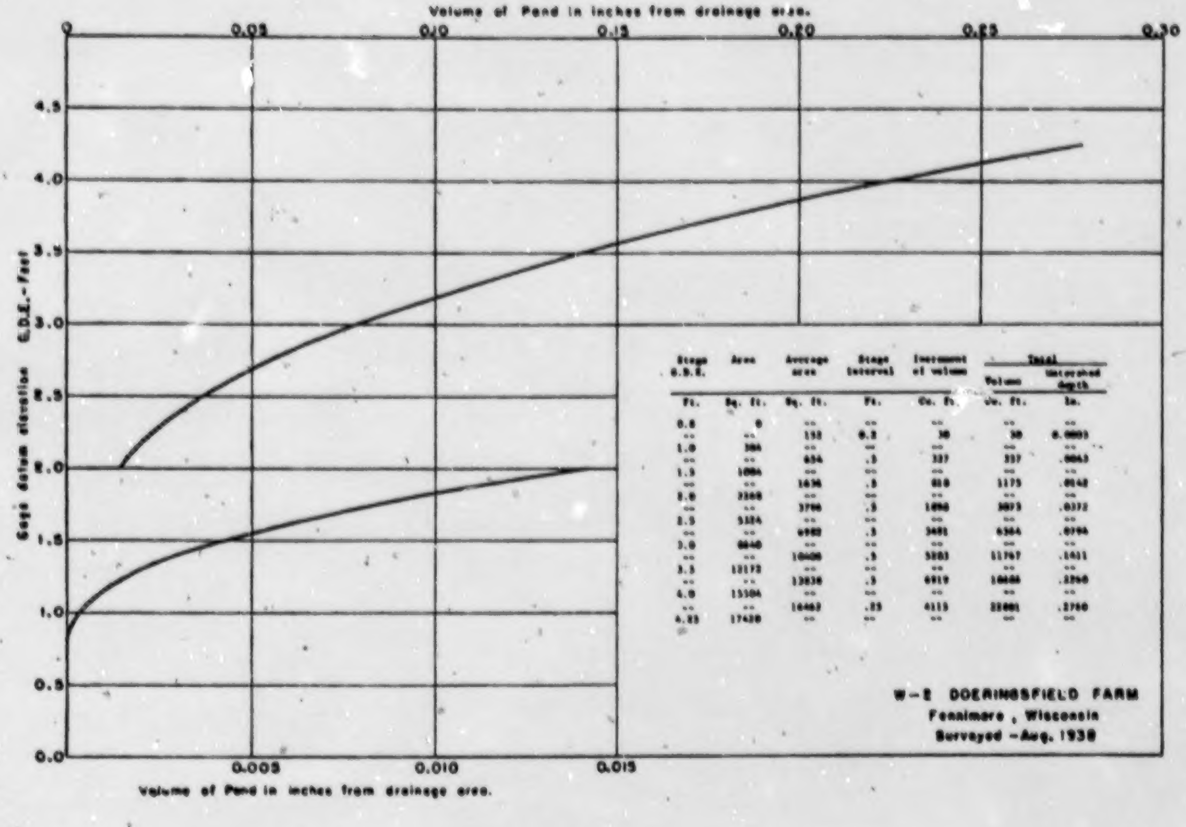
G.D.E. = Gage datum elevation
G.D.E. of zero flow over weir = 1.50
Reference: Drawing No. 5-8-5151-D

G.D.E. of original point of zero pondage = 0.8
G.D.E. of "float at rest" = 1.116
Cross sections taken August 1938

"Float at Rest" is the G.D.E. chart reading for lowest position of the float

Stage G.D.E.	Observed discharge over 3:1 weir (q_w) in cubic feet per second for each 0.01 ft. of G.D.E. stage										Stage G.D.E.	Pondage correction (q_p) in cubic feet per second for each 0.01 ft. of G.D.E. stage for a rate of change in stage of 1 ft. per minute									
Feet	0	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09	Feet	0	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09
1.10	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	1.10	7.20	7.43	7.66	7.89	8.12	8.35	8.58	8.81	9.04	9.27
1.20	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	1.20	9.50	9.74	9.98	10.2	10.5	10.7	10.9	11.2	11.4	11.7
1.30	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	1.30	11.9	12.1	12.4	12.6	12.9	13.1	13.3	13.6	13.8	14.1
1.40	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	1.40	14.3	14.5	14.8	15.0	15.3	15.5	15.7	16.0	16.2	16.5
1.50	0	T	T	0.001	0.003	0.005	0.007	0.010	0.014	0.019	1.50	16.7	17.0	17.3	17.6	17.9	18.2	18.4	18.7	19.0	19.3
1.60	.025	0.031	0.038	.046	.055	.065	.076	.088	.101	.116	1.60	19.6	19.9	20.3	20.6	20.9	21.3	21.6	21.9	22.2	22.6
1.70	.132	.149	.167	.187	.208	.230	.254	.279	.306	.334	1.70	22.9	23.3	23.7	24.1	24.5	24.9	25.3	25.6	26.0	26.4
1.80	.364	.394	.427	.462	.499	.537	.577	.619	.663	.709	1.80	26.8	27.1	27.7	28.2	28.6	29.1	29.6	30.0	30.5	31.0
1.90	.757	.807	.859	.913	.969	1.03	1.09	1.15	1.21	1.28	1.90	31.4	32.0	32.6	33.2	33.8	34.5	35.1	35.7	36.4	37.0
2.00	1.35	1.42	1.49	1.57	1.65	1.73	1.81	1.89	1.98	2.07	2.00	37.6	38.5	39.5	40.0	41.4	42.3	43.2	44.2	45.1	46.1
2.10	2.16	2.25	2.35	2.45	2.55	2.65	2.76	2.87	2.98	3.09	2.10	47.0	48.0	49.0	50.1	51.1	52.1	53.1	54.1	55.2	56.2
2.20	3.21	3.33	3.44	3.56	3.67	3.79	3.92	4.06	4.21	4.35	2.20	57.2	58.2	59.3	60.3	61.3	62.4	63.4	64.4	65.5	66.5
2.30	4.50	4.65	4.80	4.95	5.10	5.26	5.41	5.57	5.73	5.90	2.30	67.5	68.6	69.6	70.7	71.7	72.8	73.8	74.9	75.9	77.0
2.40	6.06	6.23	6.40	6.60	6.80	6.98	7.18	7.36	7.55	7.73	2.40	78.0	79.1	80.1	81.2	82.3	83.4	84.4	85.5	86.6	87.6
2.50	7.92	8.13	8.34	8.56	8.78	9.00	9.22	9.44	9.66	9.88	2.50	88.7	89.8	90.8	91.9	92.9	94.0	95.1	96.1	97.2	98.2
2.60	10.1	10.4	10.7	10.9	11.2	11.5	11.7	11.9	12.2	12.5	2.60	99.3	100	101	102	104	105	106	107	108	109
2.70	12.7	13.0	13.2	13.5	13.8	14.0	14.3	14.6	14.9	15.2	2.70	110	111	112	113	114	116	117	118	119	120
2.80	15.5	15.8	16.1	16.5	16.8	17.1	17.5	17.8	18.1	18.5	2.80	121	122	123	124	125	127	128	129	130	131
2.90	18.8	19.1	19.5	19.8	20.2	20.5	20.9	21.3	21.6	22.0	2.90	132	133	134	136	137	138	139	140	142	143
3.00	22.4	22.8	23.1	23.5	23.9	24.3	24.7	25.1	25.5	25.9	3.00	144	145	146	148	149	150	151	152	154	155
3.10	26.4	26.9	27.3	27.7	28.1	28.5	29.0	29.5	30.0	30.5	3.10	156	157	158	160	161	162	163	164	166	167
3.20	31.0	31.4	31.9	32.4	32.9	33.4	33.9	34.4	34.8	35.2	3.20	168	169	170	172	173	174	175	176	178	179
3.30	35.7	36.3	36.9	37.4	37.9	38.4	39.0	39.5	40.0	40.5	3.30	180	181	182	184	185	186	187	188	190	191
3.40	41.0	41.6	42.2	42.8	43.4	44.0	44.6	45.2	45.8	46.4	3.40	192	193	194	195	196	198	199	200	201	202
3.50	47.0	47.6	48.2	48.8	49.4	50.0	50.6	51.2	51.8	52.4	3.50	203	204	205	206	207	209	210	211	212	213
3.60	53.0	53.6	54.2	54.9	55.5	56.1	56.8	57.4	58.1	58.8	3.60	214	215	216	218	219	220	221	222	224	225
3.70	59.4	60.1	60.8	61.5	62.2	62.9	63.6	64.3	65.0	65.7	3.70	226	227	228	229	230	232	233	234	235	236
3.80	66.5	67.2	67.9	68.6	69.4	70.2	71.0	71.8	72.6	73.4	3.80	237	238	239	240	241	242	243	244	245	246
3.90	74.1	75.0	75.8	76.6	77.4	78.2	79.0	79.8	80.7	81.6	3.90	247	248	249	250	251	253	254	255	256	257
4.00	82.5	83.3	84.1	85.0	85.9	86.8	87.7	88.6	89.5	90.4	4.00	258	259	260	262	263	264	265	266	268	269
4.10	91.3	92.2	93.1	94.0	95.0	96.0	97.0	98.0	99.0	99.9	4.10	270	271	273	274	275	277	278	279	281	282
4.20	101	102	103	104	105	106	-------	-------	-------	-------	4.20	283	284	286	287	289	290	-------	-------	-------	-------

Figure 7. Computations to obtain volume of pond for various stages of elevation and pondage volumes curves, Fennimore, Wisconsin



Stage G.D.E.	Area	Average area	Stage interval	Increment of volume	Total Volume	Total Watershed depth
Ft.	Sq. ft.	Sq. ft.	Ft.	Cu. ft.	Cu. ft.	In.
0.8	0	--	--	--	--	--
--	--	152	0.2	30	30	0.0003
1.0	304	--	--	--	--	--
--	--	654	.5	327	357	.0043
1.5	1004	--	--	--	--	--
--	--	1636	.5	818	1175	.0142
2.0	2268	--	--	--	--	--
--	--	3796	.5	1898	3073	.0372
2.5	5324	--	--	--	--	--
--	--	6982	.5	3491	6564	.0794
3.0	8640	--	--	--	--	--
--	--	10406	.5	5203	11767	.1411
3.5	12172	--	--	--	--	--
--	--	13838	.5	6919	18686	.2260
4.0	15504	--	--	--	--	--
--	--	16462	.25	4115	22801	.2760
4.25	17420	--	--	--	--	--

W-2 DOERINGSFIELD FARM
Fennimore, Wisconsin
Surveyed - Aug. 1938

Table 2. Discharge values corresponding to various cross-sectional areas of the channel of approach 10 feet upstream from center of crest for triangular weirs[1]

2:1 TRIANGULAR WEIRS

1-foot head		2-foot head		3-foot head		4-foot head		5-foot head		6-foot head	
Area	Discharge	Area	Discharge	Area	Discharge	Area	Discharge	Area	Discharge	Area	Discharge
Sq. ft.	*C.f.s.*	*Sq. ft.*	*C.f.s.*	*Sq. ft.*	*C.f.s.*	*Sq. ft.*	*C.f.s.*	*Sq. ft.*	*C.f.s.*	*Sq. ft.*	*C.f.s.*
6.0	5.60	13.0	41.3	26.0	132	46	270	72	500	102	900
6.2	5.58	13.2	40.6	26.2	129	47	259	73	480	103	840
6.4	5.56	13.4	40.0	26.4	127	48	250	74	464	104	790
6.6	5.54	13.6	39.4	26.6	125	49	244	75	450	105	750
6.8	5.52	13.8	38.9	26.8	124	50	239	76	437	106	725
7.0	5.51	14.0	38.4	27.0	123	52	231	77	428	107	700
7.2	5.51	14.2	37.9	27.5	118	54	225	78	420	108	692
7.4	5.50	14.4	37.5	28.0	116	56	220	79	413	109	682
7.6	5.49	14.6	37.2	28.5	114	58	216	80	408	110	675
7.8	5.48	14.8	36.9	29.0	112	60	213	82	400	112	660
8.0	5.47	15.0	36.6	30.0	108	62	210	84	393	114	647
8.5	5.45	15.2	36.4	32.0	104	64	207	86	387	116	636
9.0	5.44	15.4	36.2	34.0	102	66	205	88	382	118	627
9.5	5.43	15.6	36.0	36.0	100	68	203	90	378	120	620
10.0	5.42	15.8	35.8	38.0	98.0	70	201	95	370	125	605
11.0	5.41	16.0	35.6	40.0	97.0	72	200	100	364	130	592
12.0	5.40	16.5	35.2	42.0	96.0	74	199	105	339	135	581
13.0	5.40	17.0	34.8	44.0	95.0	76	198	110	354	140	572
14.0	5.39	17.5	34.5	46.0	94.0	78	197	115	350	145	565
15.0	5.39	18.0	34.3	48.0	93.5	80	196	120	346	150	560
20.0	5.38	19.0	33.9	50.0	93.0	82	195	125	343	160	548
25.0	5.37	20.0	33.6	55.0	92.0	84	194	130	341	170	541
30.0	5.36	21.0	33.4	60.0	91.0	86	193	140	337	180	537
35.0	5.36	22.0	33.2	70.0	90.5	88	192	150	334	200	528
40.0	5.35	23.0	33.1	80.0	90.0	90	191	100	331	220	523
45.0	5.35	24.0	33.0	90.0	89.5	100	189	180	328	240	520
50.0	5.35	25.0	32.9	100	89.0	110	187	200	325	270	514
60.0	5.34	30.0	32.5	120	88.8	120	186	230	323	300	510
70.0	5.34	35.0	32.2	140	88.6	130	185	260	321	350	508
80.0	5.34	40.0	32.0	160	88.4	140	185	300	320	400	506
		50.0	31.8	180	88.2	170	184	325	320	450	505
		60.0	31.7	200	88.0	200	183	350	319	500	504
		80.0	31.6	220	88.0	250	183	375	319	550	503
		110.0	31.6	240	88.0	300	183	400	318	600	502
		150.0	31.6	260	88.0	350	183	450	318	650	501

3:1 TRIANGULAR WEIRS

1-foot head		2-foot head		3-foot head		4-foot head		5-foot head		6-foot head	
8.0	8.37	20.0	57.3	40.0	188	70.0	425	110	715	160	1100
8.5	8.30	22.0	54.4	41.0	180	72.0	388	115	655	162	1075
9.0	8.25	24.0	52.7	42.0	175	74.0	373	120	625	164	1050
9.5	8.22	26.0	51.5	44.0	167	76.0	360	125	605	166	1025
10.0	8.19	28.0	50.8	47.0	159	78.0	352	130	590	168	1005
11.0	8.13	30.0	50.2	50.0	154	80.0	345	135	576	170	990
12.0	8.08	32.0	49.8	52.0	152	82.0	339	140	564	172	980
13.0	8.04	34.0	49.4	54.0	150	84.0	334	145	556	174	970
14.0	8.02	36.0	49.1	56.0	148	86.0	329	150	549	176	961
15.0	8.00	38.0	48.9	58.0	147	88.0	325	155	543	178	952
20.0	7.95	40.0	48.7	60.0	146	90.0	321	160	537	180	945
25.0	7.93	42.0	48.5	62.0	145	92.0	318	165	532	185	930
30.0	7.92	44.0	48.3	64.0	144	94.0	315	170	528	190	912
35.0	7.92	46.0	48.2	66.0	143	96.0	312	175	524	200	890
40.0	7.92	48.0	48.1	68.0	143	98.0	310	180	521	210	870
45.0	7.92	50.0	48.0	70.0	142	100	308	185	518	220	858
50.0	7.92	52.0	47.9	72.0	142	105	304	190	515	230	847

See footnote at end of table.

Table 2. Discharge values corresponding to various cross-sectional areas of the channel of approach 10 feet upstream from center of crest for triangular weirs[1]--Continued

3:1 TRIANGULAR WEIRS

1-foot head		2-foot head		3-foot head		4-foot head		5-foot head		6-foot head	
Area	Discharge	Area	Discharge	Area	Discharge	Area	Discharge	Area	Discharge	Area	Discharge
Sq. ft.	*C.f.s.*	*Sq. ft.*	*C.f.s.*	*Sq. ft.*	*C.f.s.*	*Sq. ft.*	*C.f.s.*	*Sq. ft.*	*C.f.s.*	*Sq. ft.*	*C.f.s.*
60. 0	7. 92	54. 0	47. 8	74. 0	141	110	300	195	512	240	838
70. 0	7. 92	56. 0	47. 7	76. 0	141	115	297	200	510	250	830
80. 0	7. 92	58. 0	47. 6	78. 0	140	120	295	210	508	260	822
		60. 0	47. 5	80. 0	139	125	293	220	506	270	815
		62. 0	47. 5	82. 0	139	130	291	230	504	280	810
		64. 0	47. 4	84. 0	139	135	289	240	502	290	806
		66. 0	47. 4	86. 0	138	140	287	250	500	300	803
		68. 0	47. 4	88. 0	138	145	286	260	498	320	797
		70. 0	47. 3	90. 0	138	150	285	270	496	340	791
		72. 0	47. 3	95. 0	137	160	284	280	494	360	786
		74. 0	47. 3	100	137	170	283	290	493	380	782
		76. 0	47. 2	110	136	180	282	300	492	400	780
		78. 0	47. 2	120	135	190	281	350	490	450	776
		80. 0	47. 1	130	134	200	280	400	488	500	773
		85. 0	47. 1	140	134	250	277	450	486	550	770
		90. 0	47. 0	150	133	300	276	500	485	600	767
		100	47. 0	200	133	400	275	550	484	650	765
		150	47. 0	250	132	500	275	600	484		

5:1 TRIANGULAR WEIRS

1-foot head		2-foot head		3-foot head		4-foot head		5-foot head		6-foot head	
Area	Discharge	Area	Discharge	Area	Discharge	Area	Discharge	Area	Discharge	Area	Discharge
15. 0	13. 7	30	98. 0	60	315	116	590	170	1070	230	1880
18. 0	13. 6	31	96. 5	61	306	118	580	180	1015	240	1680
21. 0	13. 5	32	95. 0	62	300	120	572	190	975	250	1615
30. 0	13. 4	33	93. 5	63	295	122	565	200	950	260	1570
50	13. 2	34	92. 2	64	291	124	559	210	928	270	1530
60	13. 3	35	91. 2	65	287	126	554	220	910	280	1495
70	13. 3	36	90. 3	66	283	128	550	230	898	290	1465
80	13. 3	37	89. 5	67	280	130	546	240	888	300	1440
90	13. 3	38	88. 9	68	277	132	542	250	880	310	1424
100	13. 3	39	88. 4	69	274	134	538	260	871	320	1410
		40	88. 0	70	272	136	534	270	864	330	1398
		42	87. 2	72	268	138	531	280	858	340	1388
		44	86. 5	74	264	140	528	290	853	350	1580
		46	85. 9	76	261	145	522	300	850	360	1373
		48	85. 4	78	259	150	518	310	847	370	1366
		50	85. 0	80	257	155	513	320	844	380	1359
		55	84. 1	84	253	160	510	330	842	390	1353
		60	83. 5	88	249	170	504	340	840	400	1347
		65	83. 0	92	246	180	499	350	838	410	1341
		70	82. 7	96	244	190	494	360	836	420	1336
		75	82. 4	100	243	200	490	370	834	430	1331
		80	82. 2	110	240	210	487	380	832	440	1326
		85	82. 0	120	237	220	485	390	830	450	1322
		90	81. 8	140	234	230	483	400	828	500	1310
		95	81. 6	160	232	240	481	450	826	550	1290
		100	81. 4	180	231	250	480	500	824	600	1283
		110	81. 2	200	230	260	479	550	822	650	1278
		120	81. 0	220	229	280	477	600	820	700	1275
		140	80. 8	250	228	300	475	650	818	750	1272
		170	80. 6	300	227	400	470	700	816	800	1270
		200	80. 5	400	226	600	465	800	812	900	1270
		300	80. 5	500	226	700	465	1000	805	1000	1270

---

[1] Based on hydraulic laboratory tests made by the Soil Conservation Service at Cornell University, Ithaca, N.Y.

Table 3. Discharge values for heads up to 0.7 foot

Head (foot)	0.00	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09
2:1 TRIANGULAR WEIRS [1]										
	C.f.s.	*C.f.s.*	*C.f.s.*	*C.f.s.*	*C.f.s.*	*C.f.s.*	*C.f.s.*	*C.f.s.*	*C.f.s.*	*C.f.s.*
0	0	(2)	(2)	0. 001	0. 002	0. 003	0. 005	0. 007	0. 010	0. 013
0.10	. 017	0. 021	0. 027	. 033	. 039	. 046	. 055	. 064	. 073	. 083
0.20	. 094	. 105	. 116	. 131	. 147	. 163	. 179	. 195	. 214	. 233
0.30	. 252	. 273	. 295	. 318	. 342	. 368	. 395	. 423	. 452	. 482
0.40	. 514	. 547	. 581	. 616	. 653	. 691	. 731	. 772	. 814	. 858
0.50	. 903	. 950	. 998	1. 05	1. 10	1. 15	1. 20	1. 26	1. 32	1. 38
0.60	1. 44	1. 50	1. 56	1. 63	1. 70	1. 77	1. 84	1. 92	2. 00	2. 08
0.70	2. 16									
3:1 TRIANGULAR WEIRS [3]										
0	0	(2)	(2)	0. 001	0. 003	0. 005	0. 007	0. 010	0. 014	0. 019
0.10	. 025	0. 031	0. 038	. 046	. 055	. 065	. 076	. 088	. 101	. 116
0.20	. 132	. 149	. 167	. 187	. 208	. 230	. 254	. 279	. 306	. 334
0.30	. 364	. 394	. 427	. 462	. 499	. 537	. 577	. 619	. 663	. 709
0.40	. 757	. 807	. 859	. 913	. 969	1. 03	1. 09	1. 15	1. 21	1. 28
0.50	1. 35	1. 42	1. 49	1. 57	1. 65	1. 73	1. 81	1. 89	1. 98	2. 07
0.60	2. 16	2. 25	2. 35	2. 45	2. 55	2. 65	2. 76	2. 87	2. 98	3. 09
0.70	3. 21									
5:1 TRIANGULAR WEIRS [4]										
0	0	(2)	0. 001	0. 002	0. 004	0. 006	0. 010	0. 015	0. 021	0. 028
0.10	. 037	0. 047	. 058	. 072	. 086	. 103	. 121	. 141	. 164	. 188
0.20	. 215	. 243	. 274	. 305	. 340	. 378	. 417	. 458	. 500	. 545
0.30	. 590	. 640	. 700	. 760	. 820	. 880	. 940	1. 00	1. 07	1. 15
0.40	1. 23	1. 31	1. 39	1. 47	1. 55	1. 65	1. 75	1. 85	1. 95	2. 05
0.50	2. 15	2. 25	2. 36	2. 47	2. 59	2. 72	2. 85	3. 00	3. 15	3. 30
0.60	3. 45	3. 60	3. 75	3. 91	4. 08	4. 25	4. 42	4. 60	4. 79	4. 98
0.70	5. 18									

[1] Applicable to stations with cross-sectional areas through intake equal to or greater than 6 square feet for 1.0-foot head.

[2] Trace.

[3] Applicable to stations with cross-sectional areas through intake equal to or greater than 8 square feet for 1.0-foot head.

[4] Applicable to stations with cross-sectional areas through intake equal to or greater than 15 square feet for 1.0-foot head.

APPENDIX C

DESIGN SPECIFICATIONS FOR V-NOTCH WEIRS

DESIGN AND CONSTRUCTION OF WEIRS

The simplest weir in design and construction consists of a watertight cutoff wall that spans the stream channel, creating a pond or settling basin upstream. The ends and base of the cutoff wall are tied into bedrock or impermeable material.

A tighter container is required where the channel bottom is permeable, where bedrock is cracked or irregular, or where the stream channel does not follow naturally worn V-shaped bedrock. Here a watertight box is required--a box that is open at the top at the upstream end. The box may be equipped on the upstream end with wingwalls that extend into the sides of the streambank. These walls will funnel the streamflow into the box and, thus, serve in part as a cutoff wall. This design makes it possible to intercept all of the surface flow at the upstream edge of the box.

Where the stream gradient is low and the geology permits, a four-sided box may be sunk in the stream channel. Streamflow enters the box by dropping down a vertical wall on the upstream side.

The three types of weir basins described here are shown in figure 8. All of them have a blade mounted in a notch on the downstream wall, drain and intake pipes, instrument shelter or gagehouse, and stilling well. The watertight box is more complicated, and construction is more costly than for the cutoff wall type.

Cutoff Wall

A cutoff wall is constructed across the stream channel, with its base firmly imbedded in the impermeable bedrock. Structural views are given in figure 9.

The top of the cutoff wall is level with the top of the V-notch. At the streambanks, the cutoff wall projects 2 feet higher to provide a triangular section above the V to accomodate flows that exceed the V-notch capacity.

Watertight Box

The watertight-box type is an elaboration of the cutoff-wall design. Instead of spanning the width between natural streambanks, the cutoff wall is joined on both ends of the sidewalls (figure 10). A concrete floor forms the bottom of the basin if the natural floor is permeable. Plans are shown in figure 11.

Construction

Before construction, the site should be surveyed, and stakes should be carefully placed to guide operations. Channel alignment in relation to the position of the weir must be considered. Generally, straight flow is desirable through the weir and through a reach above the weir.

The vertical position of the structure is very important. Where the simple cutoff wall is used, one guideline is to maintain the original stream gradient above the weir basin. The vertex of the notch should ordinarily be at the elevation of the original streambed or somewhat lower. Thus, the impounded water will be contained in the basin and will not back up into the natural stream channel.

The dimensions of the basin must be determined and staked out. The width should be at least the width of the notch plus a distance on each side of the notch equal to 2.5 times the maximum head.

Determining the length of the basin is often more difficult. One objective in operating a weir is to spread the flow evenly over the whole cross-section at the upstream edge of the basin. Where this can be done, a short weir basin suffices. Generally, the flow does not enter uniformly even if efforts are made to spread it; therefore, the weir basin should be long enough to even out the flow before it reaches the stilling well intake pipes and the notch. Basins are often constructed 20 to 30 feet long for weirs with notches 2 feet high.

Where it is not feasible to dig a basin below the normal stream channel--for example, where hard bedrock forms the channel--the length of the basin will be governed by the slope of the stream channel. A channel with a gradient of one vertical unit to three horizontal units is almost ideal; it would require a basin about 25 feet long. If the stream gradient is very low, it may be impractical to use the watertight-box stream-gaging design because the length of the basin walls necessary to fulfill the hydraulic requirement would be prohibitive.

The recommended depth of the weir pond at the notch (at least 2.5 times the head below the vertex of the V), the stream gradient, and the material underlying the stream channel should also be considered in determining the length of the basin. In some cases, setting the elevation of the notch as previously described would require considerable excavation below the level of the streambed if the basin were short. If the simple cutoff wall is used, pondage corrections are necessary.

Cutoff Wall

Because one of the prime functions of the cutoff wall is to force all water within the basin to flow over the control notch, the cutoff wall must make a watertight junction with underlying natural material.

If the wall is to rest on bedrock, the stability of the wall and watertightness of the wall-bedrock junction may be achieved in one of several ways. Keys, 1 1/2 to 2 inches wide and deep, may be drilled in the bedrock. This key will add to the watertightness by creating a larger surface area at the joint; it will also secure the concrete wall to the bedrock, preventing sliding of the structure. Steel anchor pins, imbedded in both the rock ledge and the concrete wall, also secure the walls. Footings of poured concrete, perhaps 3 feet wide, may provide both stability and watertightness.

If the wall is to be built on tight subsoil, it may be well to cut trenches or keys. Care should be taken so cracks do not form and so the material is not shattered during excavation. With some subsoils, it may be advisable to pour a concrete footing considerably wider than the wall proper. The width of the footing depends on the bearing strength of the soil. Engineering advice should be sought if there is any question on this point.

Figure 8. Three types of weir basins: A, Weir basin formed by simple cutoff wall spanning stream channel; B, weir basin formed by watertight box with front wall, two sidewalls, and floor with open upstream end; C, weir basin formed by sunken watertight box with four sides and floor.

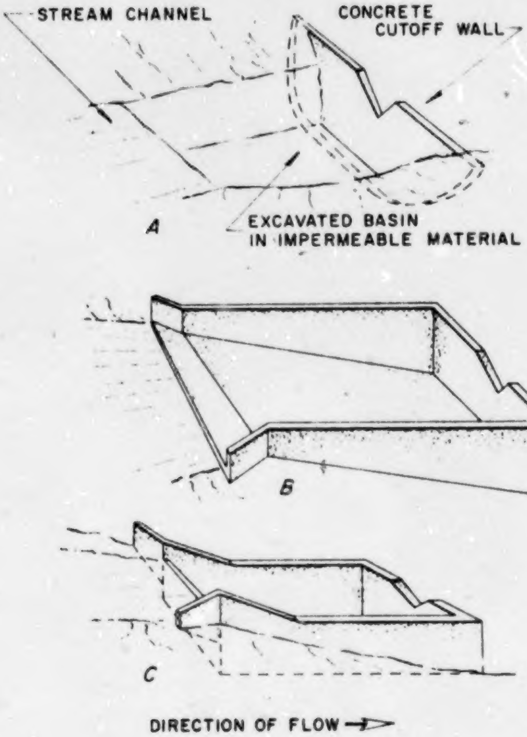

STREAM CHANNEL
CONCRETE CUTOFF WALL
A
EXCAVATED BASIN IN IMPERMEABLE MATERIAL
B
C
DIRECTION OF FLOW

Figure 9. Plans for concrete cutoff wall constructed at Fernow Experimental Forest, Parsons, W. Va.

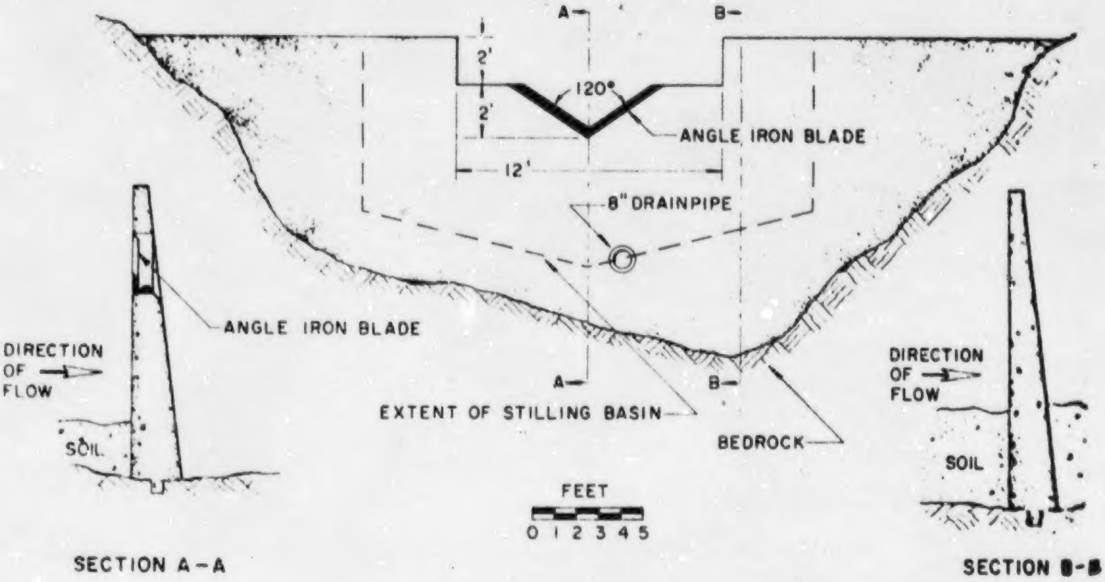

A
B
2'
2'
120°
ANGLE IRON BLADE
12'
8" DRAINPIPE
ANGLE IRON BLADE
DIRECTION OF FLOW
SOIL
A
B
EXTENT OF STILLING BASIN
BEDROCK
DIRECTION OF FLOW
SOIL
FEET
0 1 2 3 4 5
SECTION A-A
SECTION B-B

Figure 10. Schematic diagram of 120° V-notch weir, watertight design.

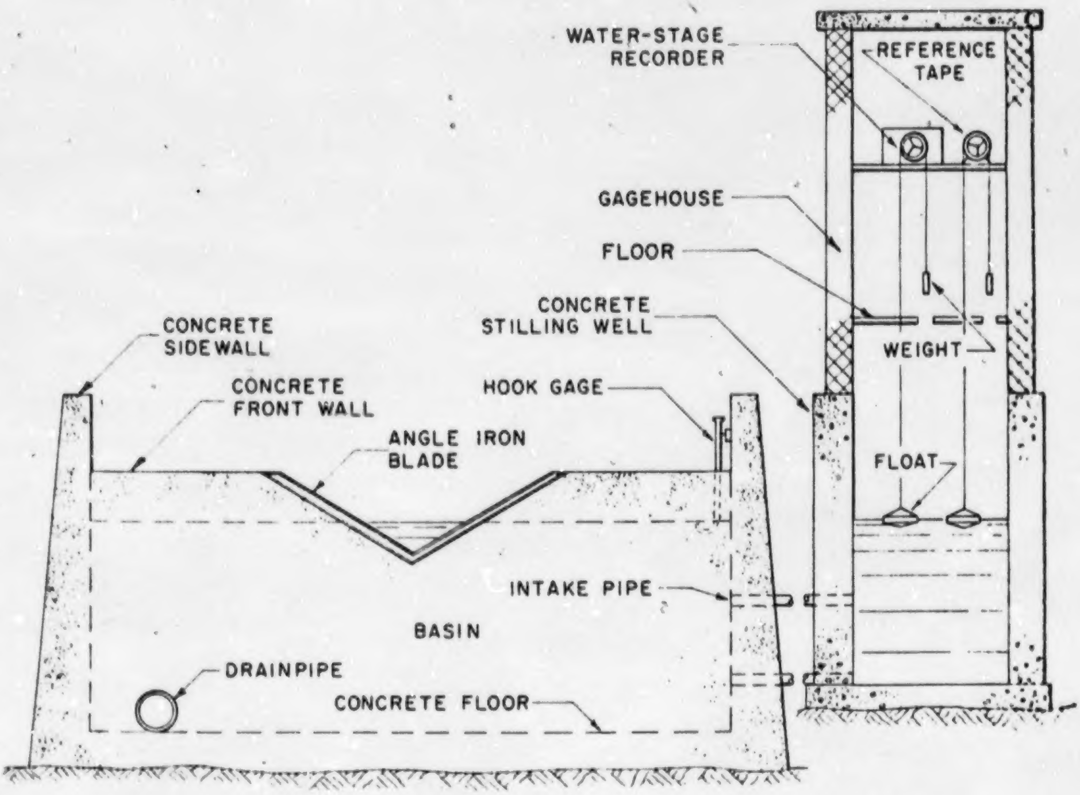
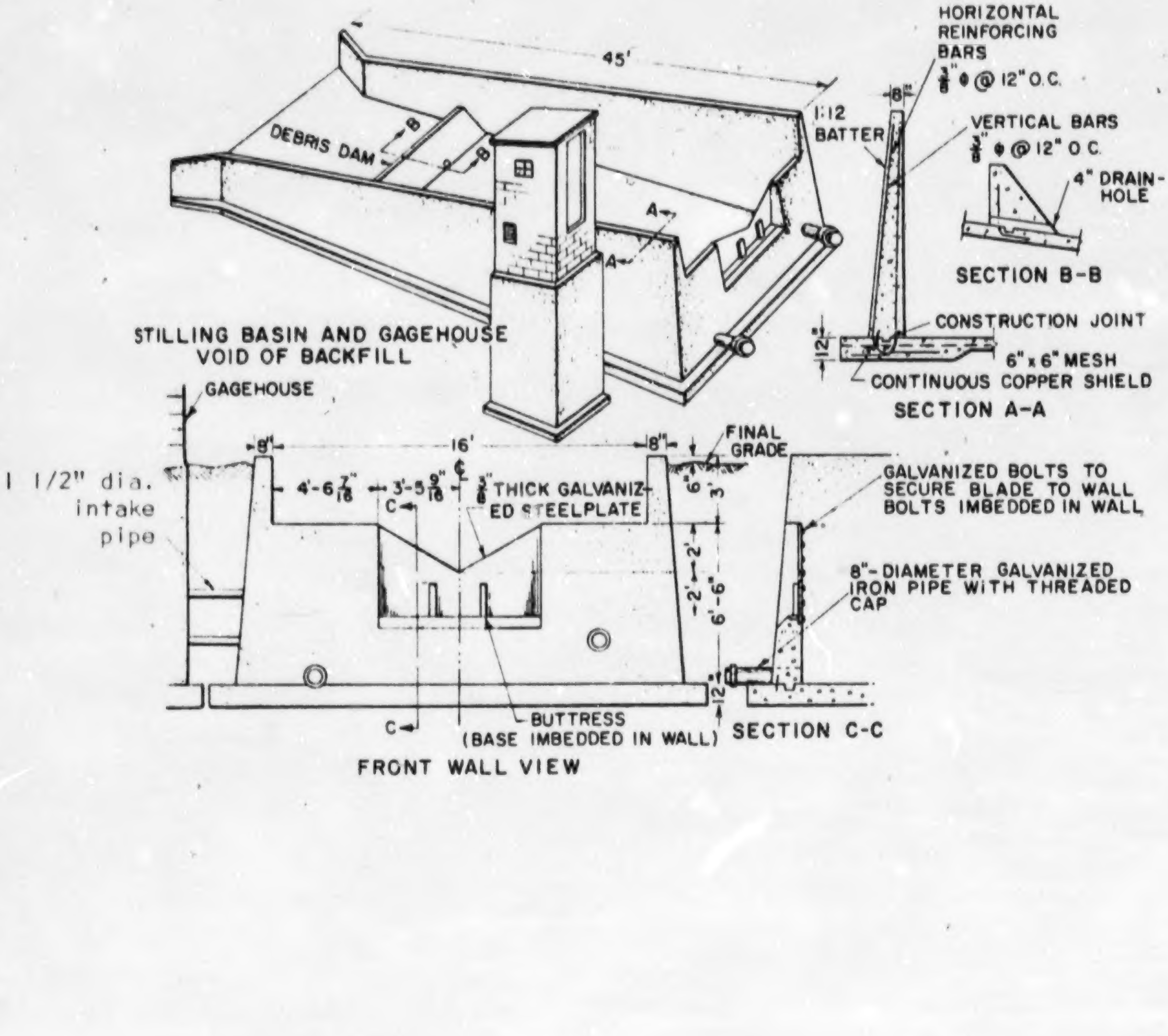
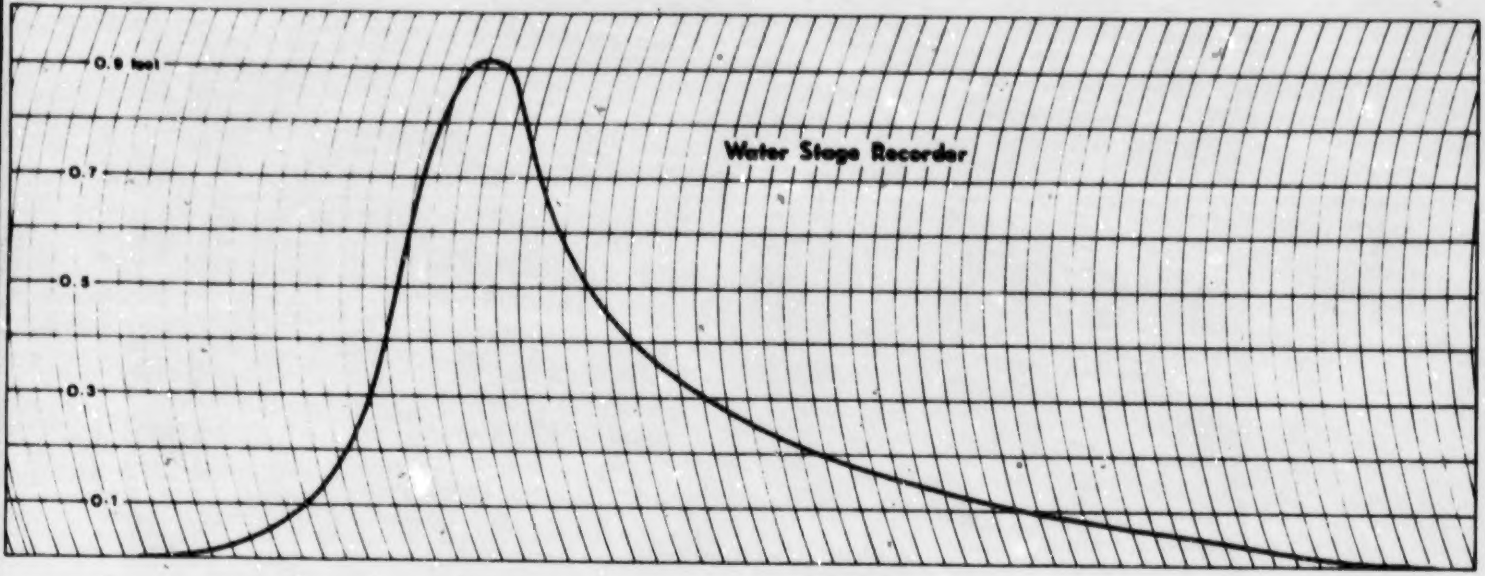

WATER-STAGE RECORDER
REFERENCE TAPE
GAGEHOUSE
FLOOR
CONCRETE STILLING WELL
WEIGHT
CONCRETE SIDEWALL
CONCRETE FRONT WALL
HOOK GAGE
ANGLE IRON BLADE
FLOAT
INTAKE PIPE
BASIN
DRAINPIPE
CONCRETE FLOOR

Figure 11. Plans for concrete weir of watertight-box design constructed at Hubbard Brook Experimental Forest, West Thornton, N.H.


45'
DEBRIS DAM
B
B
A
A
1:12
BATTER
8"
HORIZONTAL
REINFORCING
BARS
3/8" φ @ 12" O.C.
VERTICAL BARS
3/8" φ @ 12" O.C.
4" DRAIN-
HOLE
SECTION B-B
CONSTRUCTION JOINT
12"
6" x 6" MESH
CONTINUOUS COPPER SHIELD
SECTION A-A
STILLING BASIN AND GAGEHOUSE
VOID OF BACKFILL
GAGEHOUSE
1 1/2" dia.
intake
pipe
8"
16'
8"
4'-6 7/16"
3'-5 9/16"
℄
3/8" THICK GALVANIZED STEELPLATE
C
C
6"
3'
2'
2'
6'-6"
12"
FINAL
GRADE
GALVANIZED BOLTS TO
SECURE BLADE TO WALL
BOLTS IMBEDDED IN WALL
8"-DIAMETER GALVANIZED
IRON PIPE WITH THREADED
CAP
BUTTRESS
(BASE IMBEDDED IN WALL)
SECTION C-C
FRONT WALL VIEW

APPENDIX D

METHODS FOR DETERMINING RAINFALL INTENSITY AND RUNOFF FROM RECORDER CHARTS


0.9 feet
0.7
0.5
0.3
0.1
Water Stage Recorder

HYDROGRAPH COMPUTATION FROM STAGE RECORDER

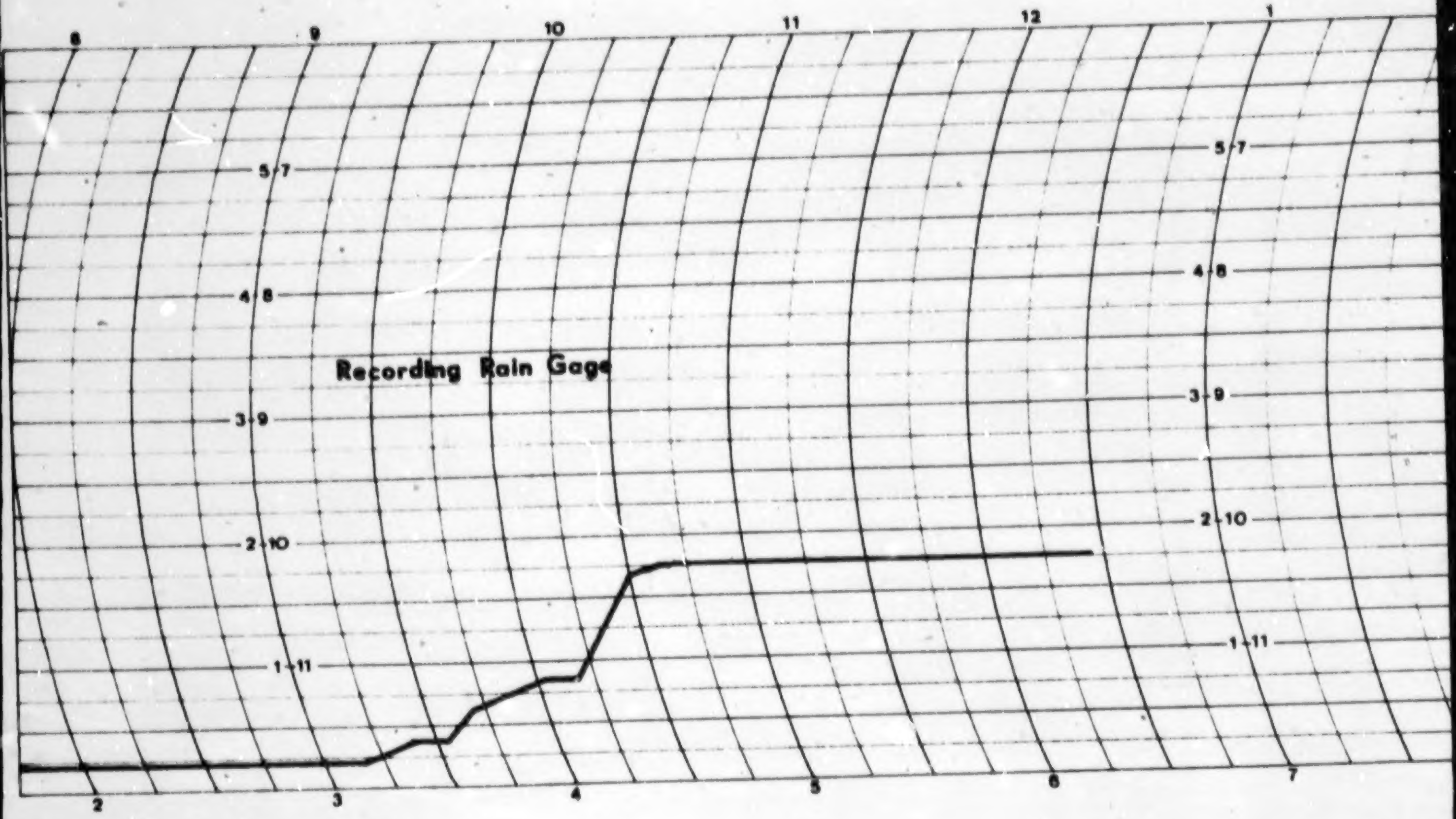
3 FOOT H-FLUME

Time (Min)	Gage Height (Ft)	Rate of Runoff (CFS)	Average Rate of Runoff (CFS)	Runoff for Time Interval (Ft^3)	Accumulated Runoff (Ft^3)
0	0.00	0.00			
20	0.01	0.001	0.0005	0.60	0.60
40	0.02	0.0021	0.0015	1.80	2.40
60	0.05	0.0105	0.0063	7.56	9.96
80	0.097	0.0329	0.0217	26.04	36.00
100	0.17	0.0766	0.0548	65.70	101.70
120	0.30	0.234	0.155	186.36	288.06
130	0.405	0.410	0.322	193.20	481.26
140	0.59	0.861	0.636	381.30	862.56
150	0.83	1.73	1.296	777.30	1639.86
160	0.92	2.15	1.940	1164.00	2803.86
170	0.902	2.06	2.105	1263.00	4066.86
180	0.85	1.82	1.940	1164.00	5230.86
190	0.76	1.44	1.630	978.00	6208.86
200	0.67	1.113	1.277	765.90	6974.76
210	0.58	0.832	0.973	583.50	7558.26
230	0.513	0.6455	0.739	886.50	8444.76
240	0.46	0.526	0.586	702.90	9147.66
260	0.343	0.301	0.414	496.20	9643.86
280	0.281	0.208	0.255	305.40	9949.26
300	0.238	0.154	0.181	217.20	10,166.46
320	0.20	0.113	0.134	160.20	10,326.66
340	0.175	0.0895	0.101	121.50	10,448.16
360	0.15	0.0686	0.079	94.86	10,543.02
380	0.121	0.0478	0.058	69.84	10,612.86
400	0.108	0.0395	0.044	52.38	10,665.24
420	0.090	0.0288	0.034	40.98	10,706.22
440	0.079	0.0229	0.029	35.22	10,741.44
470	0.060	0.0143	0.0186	33.48	10,774.92
500	0.040	0.0073	0.0108	19.44	10,794.36
530	0.020	0.0021	0.0047	8.46	10,802.82
560	0.009	0.0010	0.0016	2.79	10,805.61
590	0.003	0.00	0.0005	.90	10,806.51

Assuming a watershed of 10 acres, the total runoff would be equivalent to

$$\frac{10{,}806.51 \text{ ft}^3}{43{,}560 \text{ ft}^2/\text{acre} \times 10 \text{ acre}} \times 12 \text{ in/ft} = .2977 \text{ watershed inches}$$

The hydrograph can, of course, also be expressed in watershed inches.



8
9
10
11
12
1
5-7
4-8
3-9
2-10
1-11
Recording Rain Gage
2
3
4
5
6
7

RAINFALL INTENSITY COMPUTATION

FROM RECORDING RAINGAGE

Time (Min)	Ppt. (In)	Accumulated Ppt. (In)	Intensity (In/Hr)
0	0.00	0.00	0.00
13	0.15	0.15	0.69
23	0.00	0.15	0.00
33	0.25	0.40	1.50
53	0.25	0.65	.75
63	0.00	0.65	0.00
80	0.80	1.45	2.82
90	0.10	1.55	0.60